



Africa's Adaptation Gap

TECHNICAL REPORT



AFRICA'S Adaptation Gap

TECHNICAL REPORT

**Climate-change impacts, adaptation challenges
and costs for Africa**

The contents of this report do not necessarily reflect the views or policies of UNEP or contributory organisations. The designations employed and the presentations do not imply the expressions of any opinion whatsoever on the part of UNEP or contributory organisations concerning the legal status of any country, territory, city, company or area or its authority, or concerning the delimitation of its frontiers or boundaries.

Authors:

Michiel Schaeffer, Climate Analytics, Germany

Florent Baarsch, Climate Analytics, Germany

Sophie Adams, Climate Analytics, Germany

Kelly de Bruin, Centre for Environmental and Resource Economics (CERE), Umeå University, Sweden

Laetitia De Marez, Climate Analytics, USA

Sandra Freitas, Climate Analytics, Togo

Andries Hof, Netherlands Environmental Assessment Agency (PBL), The Netherlands

Bill Hare, Climate Analytics, Germany

Editorial Team:

Michiel Schaeffer, Climate Analytics

Richard Munang, UNEP, Regional Office for Africa (ROA)

Jesica Andrews, UNEP, Regional Office for Africa (ROA)

Sophie Adams, Climate Analytics

Cindy Baxter, Climate Analytics

Additional data and assessments:

Felix Fallasch, Climate Analytics (funding mechanisms)

Dim Coumou, Potsdam Institute for Climate Impacts Research (PIK) (data on warming, aridity)

Mahé Perrette, Potsdam Institute for Climate Impacts Research (PIK) (data on sea-level rise)

Alex Robinson, Potsdam Institute for Climate Impacts Research (PIK) (data on warming, aridity)

Reviewers:

Joe Alcamo, Chief Scientist, UNEP

Keith Alverson, Head of Climate change Adaptation, UNEP

Dorothy A. Amwata, South Eastern Kenya University

Moses Chimbari, University of Kwazulu-Natal

Ngonzo Cush, Kenyatta University, Kenya

Seybatou Diop, Institut des Sciences de la Terre, Université Cheikh Anta Diop de Dakar, Senegal

Cliff Dlamini, Stellenbosch University, South Africa

El Houssine El Mzouri, Head of Research & Development Unit, INRA Morocco

Bubu Jallow, Senior Climate Change Advisor, Gambia

Toyin Kolawole, University of Botswana

Emma T. Liwenga, University of Dar es Salaam,

Paul Mapfumo, University of Zimbabwe, Harare, Zimbabwe

Semu Ayalew Moges, Institute of Technology, Addis Ababa University, Ethiopia

Godwell Nhamo, Institute for Corporate Citizenship, University of South Africa

Maggie Opondo, Institute for Climate Change and Adaptation, University of Nairobi, Kenya

Chris Shisanya, Kenyatta University, Kenya

Shem Wandiga, University of Nairobi, Kenya

Rebecca Zengeni, University of KwaZulu Natal, South Africa

Production Team:

Richard Munang, UNEP, Regional Office for Africa (ROA)

David Ombisi, UNEP, Regional Office for Africa (ROA)

Jesica Andrews, UNEP, Regional Office for Africa (ROA)

Moses Ako, UNEP, Regional Office for Africa (ROA)

Table of Contents

Foreword	v
Key Messages	vi
Summary	viii
01 - Introduction	1
02 - Climate and Impacts projections: the Adaptation Challenge of a 4°C world	4
2.1 Climate projections for Africa	4
2.1.1 Temperature	4
2.1.2 Precipitation	4
2.1.3 Aridity	5
2.2 Impact projections	6
2.2.1 Sea-level rise	6
2.2.2 Extremes / Catastrophic events	7
2.2.3 Ecosystems	8
2.2.4 Water Resources	9
2.2.5 Agriculture	11
2.2.6 Other Market Sectors	12
2.2.7 Health	13
2.2.8 Cities	14
03 - Adaptation Options and Measures	15
3.1 Access to water	15
3.2 Agricultural food production	15
3.3 Marine and freshwater fisheries	16
3.4 Tourism	16
3.5 Health	16
3.6 Access to energy	17
3.7 Cities	17

04 - Adaptation Costs	18
4.1 The near to mid-term to 2050	18
4.2 The long term	21
4.3 Discussion	26
05 - The Adaptation Gap(s)	28
5.1 Global pledged and available funding for adaptation	28
5.1.1 Funding disbursed for adaptation, globally and in Africa	29
5.1.2 Available multilateral funding for climate change adaptation in Africa and globally	30
5.2 The funding gap	31
5.2.1 - The Emissions Gap fuelling the Adaptation Gap	31
5.2.2 The Adaptation Funding Gap	32
References	34
APPENDIX 1. overview of adaptation options and measures	40
APPENDIX 2: uncertainty and sensitivity analysis for top-down adaptation costs	43

Foreword

Africa's Adaptation Gap Report is a stark analysis of where Africa stands in relation to its adaptation goals and is a cautionary indicator of what may happen should the emissions gap remain - necessitating additional adaptation.

The Africa Adaptation Gap Report was accomplished to inform policymakers of the shortcomings and opportunities for adaptation to Climate Change in Africa. The results demonstrate how delaying action now will assuredly result in exponential costs down the road.

Adaptation costs due to past emissions are revealed to be between USD 7-15 billion annually by 2020. The report's conclusions demonstrate that - even where the emissions gap is closed and we get onto a pathway to hold warming below 2°C - by 2050 adaptation costs could hover around USD 35 billion per year. Analyses of present policies put the world on track to 3.5-4°C warming by 2100 are even more dispiriting and reveal that the cost of adaptation for Africa could reach USD 50 billion per year by 2050, still only halfway to the warming by 2100. This is hardly encouraging news for some of the world's least developed countries.

The difference in these estimates is directly linked to the commitment and ability of countries to preserve a below-2°C world. With emissions-curbing efforts an uncertain reality, adaptation may become the only option for many countries. The report illustrates that the magnitude of adaptation requirements could destabilize sectors at the heart of economic progress. In sub-Saharan Africa essential sectors like water supply, infrastructure, and agriculture will constitute the highest level of adaptation costs while in North Africa, the focus will be on infrastructure, coastal zone protection, and adapting to extreme weather events.

What are realistic options for African countries? The report sketches the technical scenarios for adaptation including the development of more drought-resistant crops, early-warning systems for floods, droughts or fires, and urban infrastructure protection measures such as seawalls, dykes, and wave breaks. The challenge will be securing the political will, technical know-how, and adequate funding.

The Report advances a number of strategies already voiced by ambitious African countries such as Sudan, Sierra Leone, Cape Verde, Chad and Gambia in their National Adaptation Programme of Actions (NAPAs). The impacts of these plans will extend from rainwater catchment, diversification of agriculture, development of aquaculture to promoting wind, solar and biogas energy.

Rising to the challenges posed by climate change will inevitably require adaptation, but the intensity of the needed adaptation measures and the scale of damages will be tightly linked subsequent to the achievements or inadequacies of efforts made to curb emissions. The Africa Adaptation Gap Technical Report is a pioneering effort, foreseen to be a stepping stone towards more comprehensive assessments, culminating in a global Adaptation Gap Report series. The Africa Report underscores the imperative of committing to adaptation aims and ensuring their realization by emphasizing the seemingly insurmountable consequences of failing to do so.

Mr. Mounkaila Goumandakoye

Director and Regional Representative

Regional Office for Africa

United Nations Environment Programme (UNEP)

Hon. Dr. Terezya Huvisa,

President

AMCEN

Key Messages

Africa faces a significant challenge in adapting to climate change with costs and damages rising rapidly with warming

Africa is a “vulnerability hot spot” for the impacts of climate change. Its adaptation challenge will grow substantially, even if the 2020 “Emissions Gap” is closed and global-mean warming held below a 2°C increase above pre-industrial temperatures.

The adaptation challenge for Africa will be much larger if the emissions gap is not closed and mitigation beyond 2020 falls short, which likely implies a 4°C warmer world at the end of the century. The level of residual damages grows substantially with increasing warming levels.

Warming limited to below 2°C still implies major adaptation costs for Africa: 4°C of warming by 2100 globally will hit the continent very hard.

On the African continent, the impacts of projected warming are relatively extreme compared to the historical climate conditions under which human and natural systems have evolved.

- Extreme weather events including droughts, floods and heat waves are likely to become both more frequent and more severe.
- With 4°C warming by 2100, sea-level rise along most African coasts could approach or exceed one metre. This will threaten communities and economic activity along some of Africa’s coastlines.
- Agricultural and fishery productivity will be diminished by changing climatic conditions.
- Human health will be undermined by the risks associated with extreme weather events and an increased incidence of transmittable diseases and under-nutrition.
- At warming exceeding 3°C globally, virtually all of the present maize, millet, and sorghum cropping areas across Africa could become unviable. However, even a warming approaching 2°C will lead to a substantial increase in the proportion of under-nourished people in sub-Saharan Africa.
- Those African populations that are already most vulnerable to climatic variability, such as the poor inhabitants of informal settlements, will become even more vulnerable.

How well Africa deals with these climate impacts, now and in the future, will be co-determined by the funding it receives.

Adaptation measures such as early warning systems and coastal zone management to counter sea-level rise offer a possibility of minimising these impacts, but Africa’s capacity to adapt depends critically on access to funding.

Developed countries have committed to provide funds rising to USD 100 billion annually by 2020 for mitigation and adaptation in developing countries.

The Cancun Agreements decided that a significant share of new multilateral funding for adaptation should flow through the Green Climate Fund (GCF). The governing instrument of the GCF and the COP requested the board to balance allocation between adaptation and mitigation. Whilst the resource allocation framework of the GCF is currently being developed, the allocation criteria will probably not be based on geographical distribution. It has been agreed that special consideration be given to the Least Developed Countries (LDCs) and Small Island Developing States (SIDS), the first being composed by many countries in Africa. Hence it is not possible at this time to assign a share of the US\$ 100 billion annual commitment by 2020 to adaptation in Africa.

Due to present and committed climate change caused by past emissions Africa is already committed to adaptation costs in the range of USD 7-15bn per year by 2020. These costs will rise rapidly after 2020, with higher levels of warming resulting in higher costs and damages

Even if adaptation funding for Africa meets adaptation costs by 2020, annual funding channelled to adaptation in Africa would need to increase further by 7% each year after 2020 to meet the adaptation challenge implied by further warming in the mid- to long-term, even if that further warming is limited to below 2°C. Estimated adaptation costs reach USD 35 billion by 2050 and USD 200 billion by the 2070s, although uncertainties are large.

With the present emission trends and policies projected to lead to warming of 3.5-4°C by 2100 funding for adaptation in Africa would need to be scaled up by as much as 10% each year from 2020 onwards.

Estimated adaptation costs reach USD 50 billion by 2050 and USD 350 billion by the 2070s. Adaptation helps to reduce damages, but does not eliminate these. Under full adaptation effort, total estimated adaptation costs plus “residual damages” reach 4% of African GDP by 2100 in a 4°C world (1% in a 2°C world), compared to an estimated 7% of African GDP in damages without adaptation to a 4°C world.

To increase confidence in meeting adaptation needs in Africa, rapid and verifiable scaling up of adaptation funding for Africa is urgent

There is currently no comprehensive database reporting finance flows from donor countries or agencies through multilateral and bilateral channels. Transparency is a prerequisite to know with any certainty whether existing and pledged funding is adequate to bridge the adaptation gap in Africa and other low-income regions.

Unless the Emissions Gap is closed, and warming limited below 2°C, rapidly rising damages, even after full adaptation, and threats to development prospects at least regionally are likely

Making up the difference between the resources required to adapt and those currently available promises a more resilient and hopeful future for Africa. Limiting warming to 1.5°C, as called for by the least developed countries and small island developing states, would further limit and reduce the adaptation costs and damages. Nevertheless, significant impacts could still be expected.

Summary

The Emissions Gap and its importance for Africa

The IPCC's Fourth Assessment (AR4) made clear Africa is a vulnerability hotspot for climate change. This was confirmed earlier in 2013 in the World Bank's report *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*, which focused on sub-Saharan Africa among three world regions.

Present pledges by individual countries to limit emissions by 2020 would, unless emissions are reduced substantially afterwards, lead to a global temperature increase of around 3.5-4°C warming by 2100. This is consistent with the UNEP Gap report (2012) and the International Energy Agency's 2012 assessment of likely future emissions, which implies that no further mitigation action would lead to a 40 percent chance of warming exceeding 4°C by 2100.

By contrast, energy-economic scenarios clearly show that stronger, technically and economically feasible, mitigation efforts worldwide can hold warming below 2°C with high probability. The inability of current emission reduction pledges to put the world on track to stay below 2°C, and the extent to which the level of emissions would be "too high" by 2020, is termed the "Emissions Gap" and annually estimated in the UNEP Emissions Gap reports.

While a 2°C global mean warming poses a major adaptation challenge, a 3.5-4°C pathway implies an even significantly larger adaptation challenge for Africa. This is explored in this report through a review of its different aspects, ranging from physical changes and impacts, to adaptation measures, costs and, finally, funding.

Likely impacts / damages from climate change

Projected warming over Africa is relatively extreme compared to the historical climate conditions and variability within which human and natural systems have evolved on this continent.

The impact projections that have appeared in the peer-reviewed literature since the AR4 (2007) point to a large and multidimensional adaptation challenge, along with significant residual damages. Many of the impacts projected for a 4°C warming scenario would be reduced if global mean warming were held below 2°C, but would still be significant and require a substantial adaptation effort.

The impacts that constitute Africa's adaptation challenge include:

- The incidence of extreme heat events that are classified as highly unusual in today's climate is projected to increase, with these events occurring in almost all summer months in 2100 in a 4°C warming scenario and becoming the "new normal" (Figure ES.1). In contrast, at 2°C warming, heat extremes that are currently highly unusual are experienced in 60-80 percent of summer months in central Africa and at lower frequencies across the rest of the continent. Limiting warming to 1.5°C will also limit further the extent and frequency of these extremes.
- With 4°C warming, annual precipitation is projected to decrease by up to 30 percent in southern Africa and by 20 percent in North Africa. Parts of north, west and southern Africa may see decreases in groundwater recharge rates of 50-70 percent as well as reductions in annual river discharge. At 2°C warming, precipitation is projected to decrease by 5-20 percent in North Africa. At this lower level of warming, changes are uncertain for the rest of the continent.
- Currently about half of Africa's land surface can be classified as arid (dry) to hyper-arid (desert). With 4°C warming, this area is projected to increase by 4 percent by 2100, while with 2°C warming the increase is only 1%.
- Sea-level rise is projected to be 10 percent higher than the global mean along African coasts – smallest along the Mediterranean coast at about 90 cm and greatest along the southeast coast at 110 cm by 2100 for 4°C warming, reducing to 60-80 cm by 2100 for 2°C warming (Figure ES.1). The most vulnerable areas in terms of population and assets at increased risk of flooding include Egypt, Cote d'Ivoire, Guinea-Bissau, Mozambique, Nigeria, Tanzania, The Gambia and Tunisia.

- Ecosystem ranges will potentially shift rapidly as warming increases, with a risk of loss of biodiversity as species may be unable to migrate to keep pace. Accelerated woody plant encroachment could limit grazing options for both wildlife and animal stock.
- Crop production is expected to be reduced across much of the continent as optimal growing temperatures are exceeded and growing seasons shortened. The areas that are appropriate for any given crop are expected to shift as local climates change. At warming exceeding 3°C globally, virtually all of the present maize, millet, and sorghum cropping areas across Africa could become unviable for current cultivars.
- Livestock production is expected to be affected by changes in feed quality and availability, water availability and increased rates of disease and heat stress.
- Fish productivity in lakes is expected to decline with increased water temperatures, high levels of evaporation and decreased nutrient concentration as a result of reduced inflow. Fishery yields are expected to decline in rivers and lakes as well as in the ocean, particularly off the coasts of West and North Africa and in the Red Sea.
- Coral reefs are projected to be at risk of regular severe bleaching nearly every other year by the 2050s in a warming pathway on track to reach 4°C by 2100, a risk that would be reduced in a 2°C world. The projected rates of bleaching even in 2°C world would still pose a significant risk to the ongoing survival of reefs in the region
- Human health will be affected, as rates of undernourishment, child stunting, vector-borne diseases (e.g. malaria), and water-borne diseases (e.g. cholera) are altered by climatic changes. Extreme weather events such as flooding and drought can also cause morbidity and mortality.
- The tourism sector could be affected through factors such as extreme summertime temperatures, loss of biodiversity and natural attractions, and damage to infrastructure as a result of extreme weather events.
- Disruptions to energy supply could occur as changes in river runoff and increased temperatures affect hydroelectric dams and the cooling systems of thermoelectric power plants.
- In many cases, urban areas are particularly exposed to a number of risks associated with climate change, including sea-level rise, storm surges and extreme heat events. Informal settlements are highly vulnerable to flooding and the poor urban populations have been found to be the most vulnerable to elevated food prices following disruptions to agricultural production.

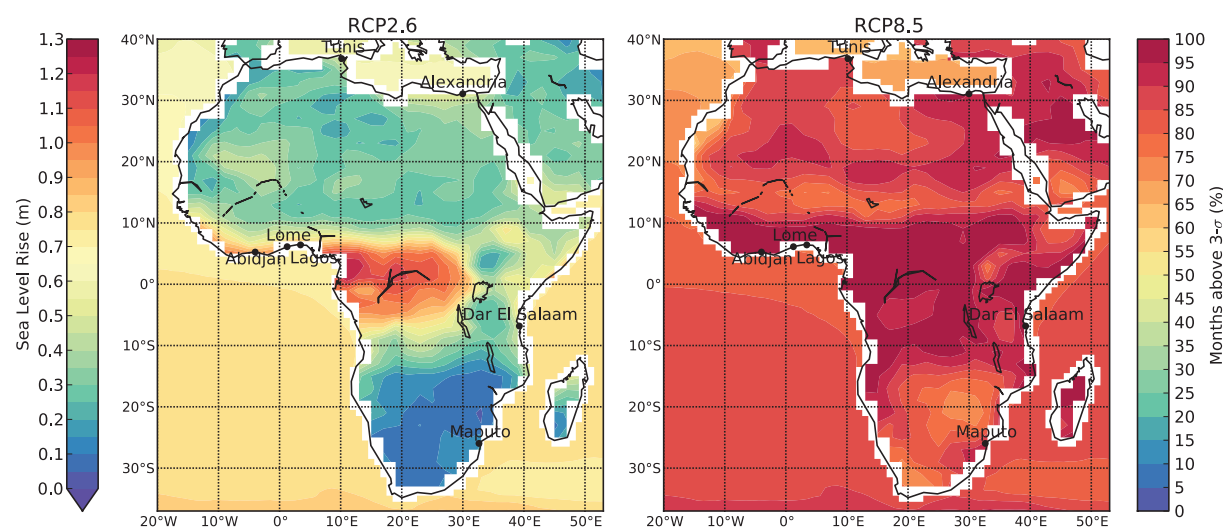


Figure ES.1 Projections for sea-level rise above present-day levels (ocean – left legend) and warming compared to present-day extremes (land – right legend) for 2100. A 2°C warming scenario (RCP2.6) is shown on the left; a 4°C warming scenario (RCP8.5) is shown on the right. Source: PIK; (Schellnhuber et al., 2013)

Adaptation measures required

The capacity of African communities to cope with the effects of climate change on different economic sectors and human activities is expected to be significantly challenged, and potentially overwhelmed, by the magnitude, and rapidity of onset, of the impacts such as those illustrated above.

To reduce the magnitude of the impacts and their repercussions for African livelihoods, adaption measures at different levels, from households to national and regional levels, are being planned and implemented and need to be further supported and strengthened.

These include, for example:

- The development of early-warning systems for floods, droughts or fires to help populations anticipate and prepare for the occurrence of extreme events
- Irrigation, improvement in water storage capacity, reforestation to protect surface water systems, sustainable use of groundwater resources, desalinisation of seawater, and rainwater catchment and storage to maintain sufficient and reliable access to freshwater for human and agricultural needs.
- City infrastructure protection measures such as seawalls, dykes, wave breakers and other elements of coastal zone management, as well as city-level food storage capacity and urban agriculture to enhance food security, and improving design and drainage technology of sanitation facilities to reduce the risk of water-borne diseases in the aftermath of extreme weather events.

Adaptation measures are considered either “soft” adaptation measures, where they involve natural capital or community control; or “hard” adaptation measures, where adapting a sector or a community requires the construction of new and capital-intensive infrastructure. The majority of the adaptation measures require an anticipatory and planned approach and large investments. The need for planned capital-intensive adaptation is greater at high than low warming levels.

The cost of adaptation for Africa

The process of estimating adaptation costs according to various climate scenarios is complex and involves many uncertainties. Nevertheless, several studies have projected the costs of adaptation measures such as those listed above.

For the near term, estimates by the World Bank (2010b) offer a useful breakdown across sectors on the regional level. For the Sub-Saharan Africa and North Africa/Middle East regions, annual adaptation costs by 2020 for a warming of about 1°C globally above pre-industrial amount to about USD 13 and 2 billion, respectively. These costs increase rapidly to around USD 24 and 5 billion, respectively, by 2040 for a warming approaching 2°C globally.

In Sub-Saharan Africa, the highest adaptation costs are projected to be needed in the water supply, coastal zone protection, infrastructure, and agriculture sectors. For Middle East & North Africa, the focus of adaptation is in infrastructure, coastal zone protection, and adapting to extreme weather events.

In a below 2°C warming pathway, Africa is still confronted with considerable impacts as described above and Africa’s long-term adaptation costs are estimated at around USD 35 billion a year by 2050 and USD 200 billion a year by the 2070s (Figure ES.2 – left panel). Beyond the 2070s, virtually all adaptation costs in a 2°C world are targeted at limiting damages from sea-level rise, as this continues even as warming stabilises at below 2°C, or even starts to decline.

In a 3.5-4°C warming pathway, estimated adaptation costs for Africa are considerably higher at around USD 45-50 billion a year by 2050 and USD 350 billion a year by the 2070s. Across all time periods, approximately half of this is for adaptation to sea-level rise, less than 10% for autonomous adaptation measures and the rest for other anticipatory measures.

In a 2°C world, annual adaptation costs plus residual damages (those damages not avoided by adaptation) are estimated to be limited to about 1% (assuming full adaptation effort) of 2100 African GDP (Figure ES.2 – right panel).

These costs are projected to increase fourfold to about 4% of Africa’s GDP under presently planned and implemented mitigation measures, assuming full adaptation effort. Without adaptation, total damages would reach 7% of Africa’s GDP for this scenario, a clear illustration of the potential for adaptation measures to significantly reduce levels of damage and reduce the overall costs.

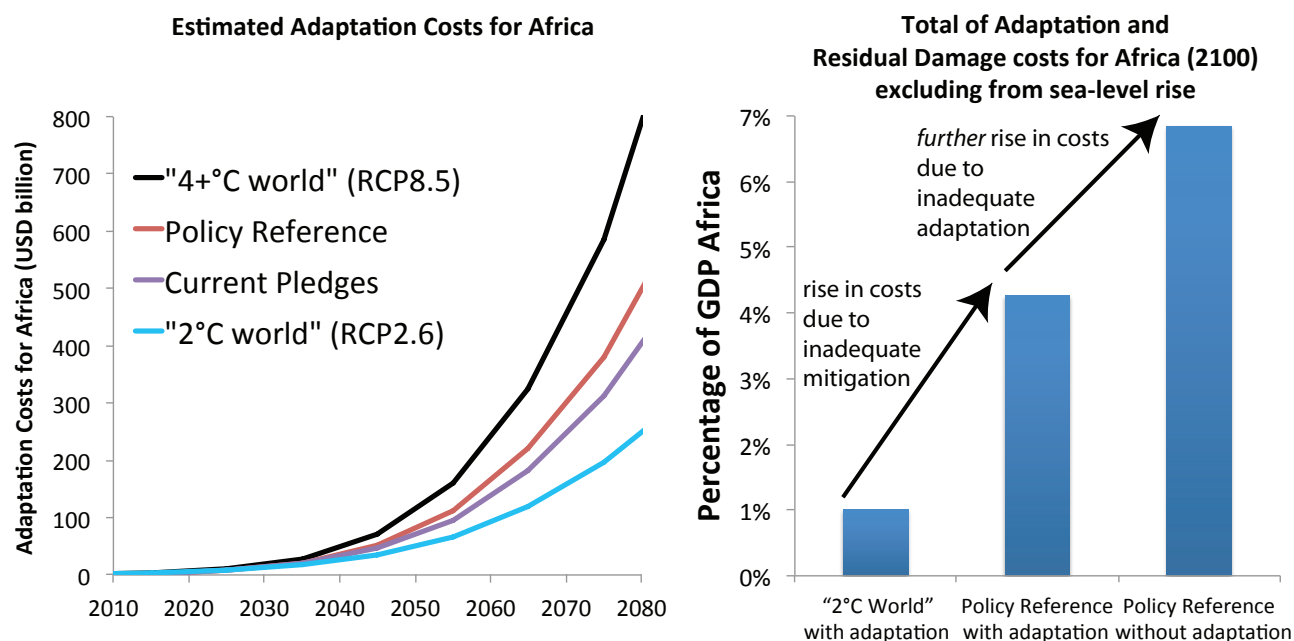


Figure ES.2 Left panel: Estimated adaptation costs for Africa for four scenarios. Right panel: Estimated total of annual adaptation costs and residual damages (part of damages not avoided by adaptation) expressed as a percentage of GDP for Africa by 2100. If the Emissions Gap is closed and global-mean warming is kept below 2°C, total adaptation costs plus residual damages can be limited to 1% of GDP in Africa by 2100. However, total adaptation and residual damages costs increase rapidly if the Emissions Gap is not closed (Policy Reference Scenario) and warming increases to 3.5-4°C. If in this high-warming case the Adaptation Funding Gap is not closed either, damages may reach 7% of GDP in Africa by 2100.

Africa's Adaptation Funding Gap

When developed countries signed the United Nations Framework Convention on Climate Change in Rio de Janeiro, 1992, they committed, under Article 4.4 to support developing countries to adapt to climate change impacts:

"The developed country Parties and other developed country parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects."

Traceable funding disbursed in Africa for climate change adaptation through bilateral and multilateral channels for the years 2010 and 2011 amounted to USD 743 and 454 million, respectively, although this figure does not fully account for the funding channelled through Development Finance Institutions, for example the World Bank, or national development banks.

To meet the adaptation costs estimated in this report for Africa by the 2020s, funds disbursed annually would need to grow at an average rate of 10-20% a year from 2011 to the 2020s. There is currently no clear, agreed pathway to provide these resources.

The UNFCCC's developed country Parties have committed to provide funds rising to US\$ 100 billion annually by 2020, from public and private sources, for both adaptation and mitigation actions in across all developing countries by 2020. Rules drawing up the allocation of funding for adaptation have yet to be defined and are to be negotiated through the Green Climate Fund (GCF) and the UNFCCC.

At this stage there is no clear sense of how much of these funds would benefit countries in the African region, nor of the likely allocation between adaptation and mitigation funding. Until these issues are resolved it is not possible to assign a share of the US\$ 100 billion annual commitment by 2020 to Africa.

Assuming funding for adaptation efforts in Africa reached adequate levels by 2020 and assuming the world gets on track to limit warming to below 2°C, annual funding for adaptation efforts in Africa still needs to rise a further 7% a year from

the 2020s onwards to keep pace with continuing sea-level rise and warming peaking below 2°C after the 2050s. This is considerably less than the funding challenge if the current mitigation efforts were not increased, and warming reached 3.5-4°C by 2100. In this case, the scaling up of annual funds would need to be 10% every year after the 2020s.

Reporting and verification of financial support is key

Ensuring the measurement, reporting and verification of financial support delivered to developing country Parties is a key element. The limitations and caveats of funding data discussed in this report illustrate that access to accurate and reliable data on support for adaptation and mitigation in developing countries is particularly complex.

There is currently no comprehensive database reporting finance flows from donor countries or agencies through multilateral and bilateral channels. Transparency is a prerequisite to know with any certainty whether existing and pledged funding is adequate to bridge the adaptation gaps in Africa and other low-income regions.

Common reporting format tables adopted in Doha have yet to be improved, especially on how much of private investment leveraged through public funding can be accounted toward developed country Party commitments. Methodological work is being undertaken by the Organisation for Economic Co-operation and Development (OECD) and the result of the work is expected to be discussed under the UNFCCC. Symmetrically, in order to ensure that the funding for climate change adaptation is efficiently used, a monitoring and evaluation system on the implementation of adaptation projects in developing countries should be strengthened through capacity-building and technical assistance.

To increase confidence in meeting adaptation needs in Africa, scaling up of traceable adaptation funds for Africa is urgent.



01 Introduction

Recent studies and reports show that the projected increase in greenhouse gas emissions in the atmosphere over the 21st century will have detrimental and disruptive effects on human and economic activity. The costs of the impacts will increase at different rates depending on the emissions pathways associated with various potential development trajectories. As the severity of impacts grows, sustaining human and economic activity will require adaptation to limit the adverse effects of climate change. Adaptive measures such as building sea dykes, constructing climate-proofed water infrastructure or developing early-warning systems for small-scale farmers will require funding, technical and technological capacity and human resources – factors which are together known as adaptive capacity.

Africa is anticipated to be the most negatively affected continent on the planet due to a combination of particularly severe projected impacts and relatively low adaptive capacity (e.g. IPCC AR4). The need for adaptation is expected to be high in Africa, especially in light of the existing deficit in adaptation to current climate variability. To the best of our knowledge, there are no studies effectively estimating the adaptation needs, options and costs for different emission scenarios and associated temperature pathways.

The Cancun climate agreements specify a long-term global goal of limiting global warming to 2°C above pre-industrial temperatures, with a provision to consider revising this to 1.5°C. However, current international pledges by countries to reduce emissions fall short of what is needed to achieve these goals. For a series of reports, UNEP convened researchers who showed global emissions by 2020 are projected to be too high under business-as-usual and current-pledges pathways, compared to “cost-optimal”¹ emission pathways that limit warming to 1.5 and 2°C in the long term (UNEP 2010, 2011, 2012; van Vuuren 2011 – blue line in Figure 1.1). UNEP (2012) estimated the difference by 2020 – the “Emissions Gap” – at about 8-13 GtCO₂/yr, noting that if this gap is not closed by further reducing emissions by 2020 – and no compensation takes place beyond 2020 – warming by 2100 under “current pledges” would reach 3.5-4°C² above pre-industrial levels. Such high levels of likely warming by 2100 are consistent with the most recent generation of energy-economic models estimates of emissions in the absence of further substantial policy action (business as usual), with the median projections reaching a warming of 4.7°C above pre-industrial levels by 2100, and a 40 percent chance of exceeding 5°C (Schaeffer et al. 2013). Assessments based on recent trends in the world’s energy system by the International Energy Agency in its World Energy Outlook 2012 indicate global-mean warming above pre-industrial levels would reach 3.8°C by 2100.

As one of the research teams that participated in the UNEP (2010, 2011, 2012) exercises, we estimated warming under current pledges to be at the lower end of this range by 2100 (Schellnhuber 2012), as shown in Figure 1.1 (purple line). This estimate, however, also includes pledges for emission reductions after 2020, for any countries that have made such pledges, for example through 2050. Also, this scenario is relative to a Policy Reference scenario (red line) that includes implemented and planned policies leading to lower emission levels than most “business as usual” estimates in the literature (e.g. shaded area and black line). A higher reference scenario would lead to a higher warming estimate for current pledges as well.

The central scenario used in Chapters 4 and 5 for adaptation cost estimates is the Policy Reference scenario (red line in Figure 1.1), leading to 3.8°C warming above pre-industrial by 2100. This scenario is overall most consistent with the range of mitigation-policy assessments discussed above.

The Emissions Gap thus leaves a large “temperature gap” between the roughly 3.5-4°C warming by 2100, implied by a range of mitigation-policy scenarios and the 1.5-2°C that would technically and economically be achievable (e.g. blue line in Figure 1.1).

1 Even though current pledges would lead to 2020 emissions that are too high for a “cost-optimal” pathway in terms of limiting 21st century warming to 2°C at overall least cost to the global economy, a range of alternative emission pathways has been identified in literature that still limits warming to 2°C, at higher overall cost and higher risks of non-achieving climate targets. UNEP (2012) notes “... it is expected that scenarios with higher global emissions in 2020 are likely to have higher medium- and long-term costs, and – more importantly – pose serious risks of not being feasible in practice”. In this report, as in the UNEP Emissions Gap reports, we will assess the gap in terms of what current pledges achieve, not what future additional pledges possibly might achieve.

2 This applies for the “unconditional pledges, strict rules” case in UNEP (2012).

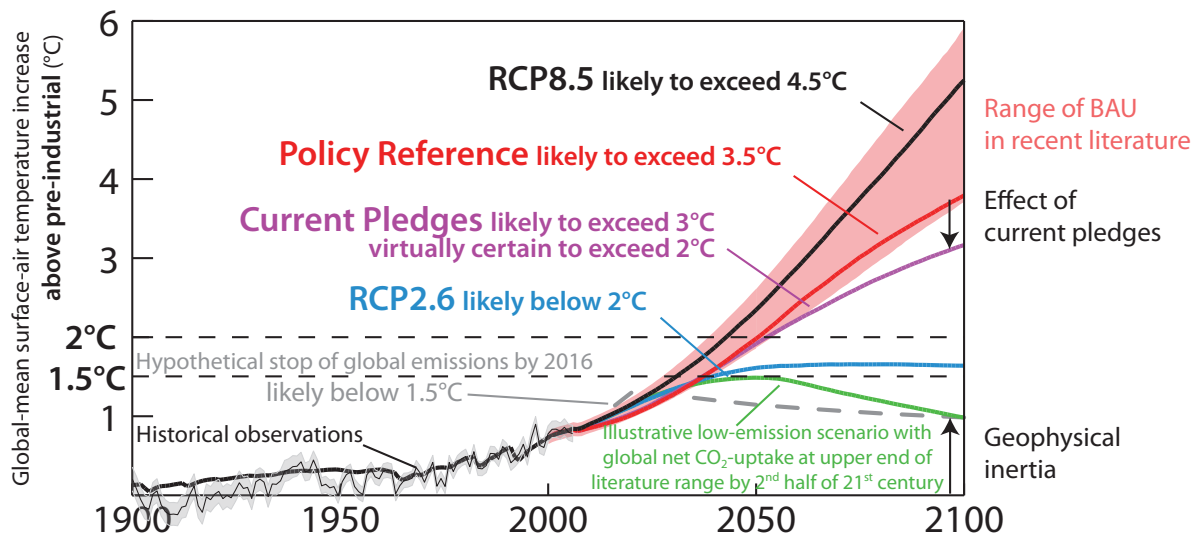


Figure 1.1 Median estimates (lines) from probabilistic temperature projections for a nonmitigation emission scenario (RCP8.5 prepared for IPCC Fifth Assessment Report – Riahi et al 2011) and Policy Reference (including implemented and planned mitigation – update from Rogelj et al. 2010), both of which come close to, or exceed by a substantial margin, 4°C warming by 2100. The shaded area shows the range of business-as-usual and policy reference scenarios in the recent literature (Schaeffer et al 2013). The results for these scenarios are compared to scenarios in which current pledges are met and to low-emissions mitigation scenarios holding warming below 2°C with a 50 percent chance or more (Hare et al 2011; Rogelj et al. 2010; Schaeffer et al 2012; RCP2.6 prepared for IPCC Fifth Assessment Report – van Vuuren et al 2011). A hypothetical scenario is also plotted for which global emissions stop in 2016, as an illustrative comparison against pathways that are technically and economically feasible. The spike in warming after emissions are cut to zero is due to the sudden removal of the shading effect of sulphate aerosols.

The higher levels of warming under current pledges would lead to greater impacts and damages, and would pose a larger challenge to adaptation, compared to a long-term limit of 1.5 or 2°C. This report considers some aspects of the “Adaptation Gap”, defined as the difference between what is needed in terms of adaptation and what is currently realised in terms of, among others, access to funds, capacity building, and monitoring and evaluation systems. The “need” for adaptation in Africa is partly related to the Emissions Gap, i.e. the need would be higher for a larger Emissions Gap and hence the Adaptation Gap would be larger (assuming a fixed level of adaptation measures). Reducing the Adaptation Gap might be achieved both by closing the Emissions Gap and by increasing adaptation efforts. Note the Adaptation Gap would not necessarily be closed were the Emissions Gap to be closed, because a (smaller) adaptation challenge would remain even at 1.5-2°C warming, as shown in this report.

Adequate funding is only one element of a range of aspects that also include the adaptation challenge posed by physical impacts, measures and institutions required for implementation of adaptation options. This report assesses a series of elements that together constitute an Adaptation Gap for Africa.

The first element consists of the adaptation challenges for Africa caused by the global Emissions Gap. This challenge is illustrated in Chapter 2 by an overview of the impacts projected to be felt across Africa in a “4°C world” as compared to a “2°C world”. This overview of impacts in sectors such as agricultural production and water resources in a “4°C world” serves to illustrate the additional adaptation challenge for Africa posed by such higher warming scenarios, compared to the smaller adaptation challenge associated with an emissions pathway leading to around 2°C global warming by 2100.

Chapter 3 offers insights into how a range of adaptation measures could partly limit the damages and impacts summarised in Chapter 2. It provides key examples of “on the ground” adaptation options and measures, with a focus on the African Least Developed Countries (LDCs). LDCs are particularly vulnerable to climate change and are expected to have to rely more heavily on international adaptation funding mechanisms.

Scaling up from specific adaptation options, a third element in identifying the Adaptation Gap for Africa is an estimate of the total adaptation costs, or financial needs, under various emission scenarios. Chapter 4 offers such estimates for the warming levels and pathways illustrated in Figure 1.1. Although uncertainty in these cost estimates is large, sectoral assessments for the near- to mid-term are offered, as well as a longer-term perspective that is particularly sensitive to long-term warming differences between emission scenarios, hence sensitive to the size of the remaining Emissions Gap.

The difference between adaptation costs implied by a “4°C world” and a “2°C world” is a part of the Adaptation Funding Gap directly caused by the Emissions Gap.

Finally, Chapter 5 provides an estimate of the Adaptation Funding Gap, in terms of the difference between adaptation costs and proposed and/or disbursed funding. Again this is assessed by necessity for different warming scenarios, in which the identified Adaptation Funding Gap for a 1.5 and 2°C pathway is associated with a zero Emissions Gap, while the Adaptation Funding Gap for pathways reaching 3.5°C to 4°C is implied by a remaining Emissions Gap of the size estimated in the UNEP Emissions Gap reports. In the context of a discussion of the many uncertainties and caveats involved, estimates will be provided of the rate by which currently disbursed funding for adaptation measures in Africa needs to be scaled up to meet the adaptation costs under a 2°C scenario, as well as the higher costs under 3-4°C scenarios.



02

Climate and Impacts projections: the Adaptation Challenge of a 4°C world

A range of emissions scenarios are used in climate change modelling to identify potential changes in climatic factors such as temperature, precipitation, extreme weather events, ocean acidification and sea-level rise, as well as potential associated impacts on human sectors. The highest emissions scenario used in the upcoming IPCC Fifth Assessment Report (AR5), RCP8.5 (black line in Figure 1.1), is associated with global average sea-level rise of more than 1 m by the end of the century and unprecedented summer heat over 60% of the land surfaces, for example. The lowest emissions scenario used in the IPCC AR5, RCP2.6 (blue line in Figure 1.1), is associated with sea-level rise of less than 70cm and a less than 30% likelihood of unprecedented summer heat.

This chapter will focus on climate projections for Africa and the related impacts at different levels of warming.

2.1 Climate projections for Africa

2.1.1 Temperature

A warming trend in Africa has been observed since the 1960s and this is expected to continue as global mean temperatures rise mostly consistently across the continent. With global-mean warming of 4°C above pre-industrial levels by the end of the century, monthly summer temperatures across Sub-Saharan Africa are projected to increase by 4-6°C above present-day temperatures, and reach 5-7°C over North Africa (Schellnhuber et al., 2013). These increases are limited significantly to around 1°C above present-day temperatures in a scenario approaching 2°C globally by 2100.

2.1.2 Precipitation

Global models indicate an increase in precipitation in the tropics and a decrease in the sub-tropics. The northern and southern regions of Africa are projected to experience particularly strong declines, with a projected decrease in annual precipitation by 5-20% along the Mediterranean coast in a scenario approaching 2°C globally (Milano & et al, 2013). For 4°C global warming, a decrease of 20% in North Africa (Christensen et al., 2007) and a decrease of 30% in southern Africa (Schellnhuber et al., 2013) compared to the present is projected. In contrast to the Mediterranean coast, precipitation changes at 2°C warming in southern Africa are uncertain, with no clear sign of change in total annual precipitation.

Tropical Africa presents a more complex picture. The IPCC AR4 stated that tropical Africa could see an annual increase, one that is projected to be greatest in East Africa, where annual precipitation could increase by 5-20% for 3-4°C warming (Christensen et al., 2007). These findings are consistent with the projections of (Schellnhuber et al., 2013), which indicate greater certainty and a stronger signal with 4°C warming compared to 2°C warming. Uncertainty about the direction of future change in precipitation is particularly large for tropical West Africa (Giannini, A., Biasutti, M., Held, I. M., & Sobel, 2008). The IPCC AR4 found changes in annual precipitation to range between -5 and +5% (Christensen et al., 2007), comparable to the projections by (Schellnhuber et al., 2013) for both warming scenarios.

2.1.3 Aridity

Aridity is a measure of the long-term balance in water supply and demand, indicating conditions under which certain crops and plants would thrive and others would not. Under 4°C warming, aridity across Africa is projected to increase strongly, mainly driven by temperature increases that raise the evapotranspiration “demand” of plants, not compensated by a sufficient increase in precipitation, or even amplified by a projected decline in precipitation. This increased aridity is shown in Figure 2.1 (right panel) by the more than 40% increase in the aridity index over much of North Africa, and up to 30% in southern Africa and on the south coast of West Africa by 2071-99 compared to 1951-80. This is more than double the aridity change projected under 2°C warming (Schellnhuber et al., 2013).

Aridity is projected to decrease in parts of the Horn of Africa under 4°C warming with a 30% increase in the aridity index. However, particular uncertainty remains for this part of East Africa, where regional climate model projections tend to show a decrease in precipitation (Schellnhuber et al., 2013), which would be associated with an increase in the Aridity Index, in contrast to the results from global climate models (GCMs) presented here.

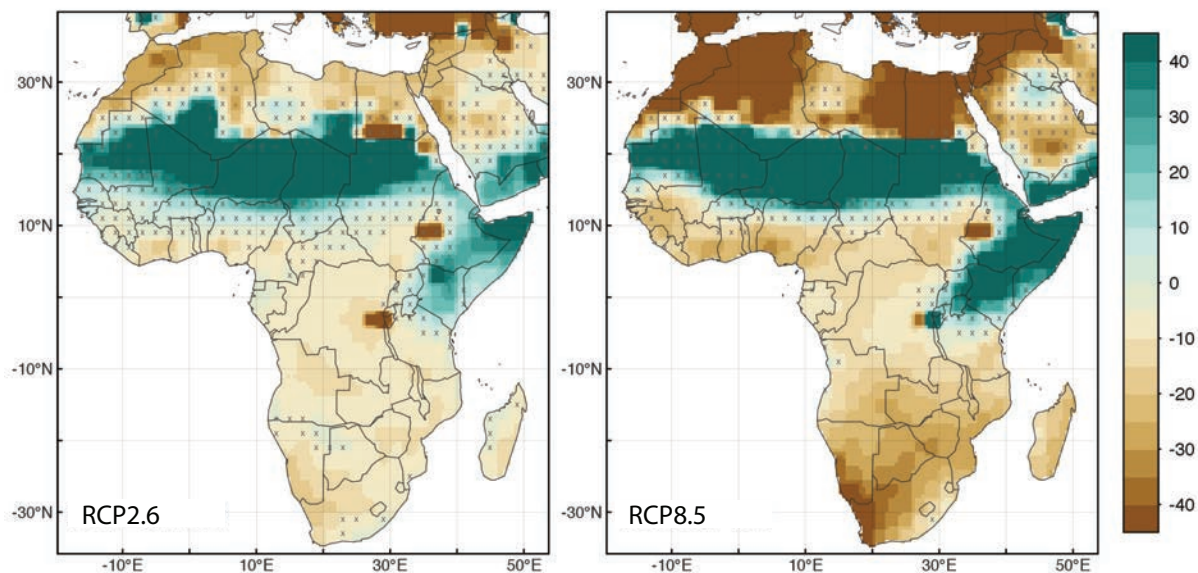


Figure 2.1 Projections for change in annual Aridity Index. Multi-model mean of the percentage change in the annual Aridity Index under 2°C warming (RCP2.6 scenario – left panel) and 4°C warming (RCP8.5 scenario – right panel) above pre-industrial for Africa by 2071–2099 relative to 1951–1980. Note that a negative change corresponds to a shift to more arid conditions. In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched areas, 2/5 (40 percent) of the models disagree. Particular uncertainty remains for East Africa, where regional climate model projections tend to show a decrease in precipitation, which would be associated with an increase in the Aridity Index, in contrast to the results from global climate models (GCMs) presented here. Note decrease in aridity does not necessarily imply more favorable conditions for agriculture or livestock, as it may be associated with increased flood risks. Note finally that the large relative change over the Sahara represents a small absolute change compared to a very low base value. Source: PIK; (Schellnhuber et al., 2013).

Due to these changes, the total surface area classified by Aridity Index as hyper-arid (desert) and arid (dry) land in Africa is projected to increase by 4% for 4°C warming by 2100 (Figure 2.2), with sub-humid lands and lands without a structural moisture deficit decreasing in area by 5% each. This compares to a much smaller increase in area of hyper-arid and arid land of 1% under 2°C warming by 2100.

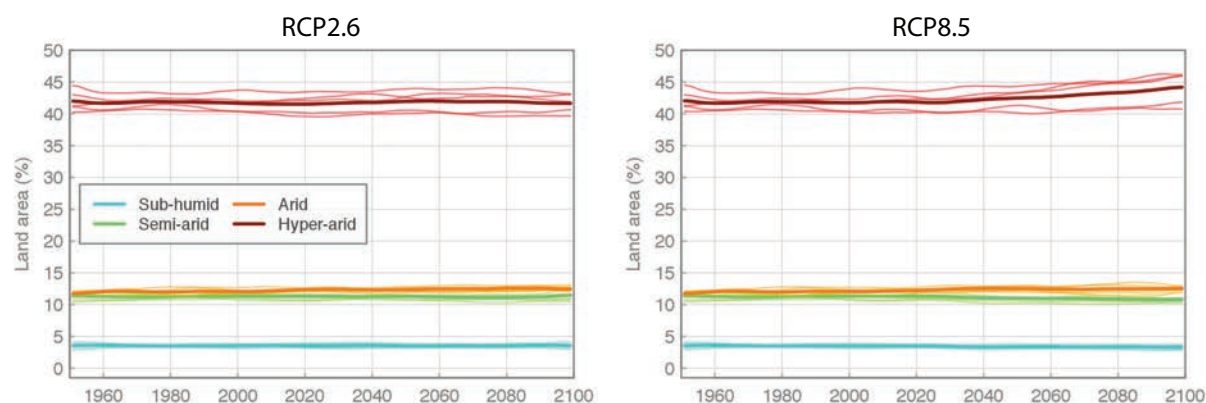


Figure 2.2 Projections for percentage of land surface in Africa with a structural moisture deficit for scenarios leading to 2°C (left) and 4°C warming by 2100 (right) above pre-industrial, for aridity categories defined by Aridity Index (sub-humid, semi-arid, arid and hyper-arid).

2.2 Impact projections

2.2.1 Sea-level rise

By the end of the century sea-level rise is expected to be approximately 10% higher along Africa's coastlines than the global mean (Schellnhuber et al., 2013). However, the rise is not homogenous along the coastline of the continent (Figure 2.3 over oceans). For example, it is projected to be higher in southern Africa than in West Africa and particular North Africa. West Africa is projected to experience sea levels elevated in the 4°C warming scenario RCP8.5 by 85-125cm by the period 2080-2100, compared to the baseline period of 1986-2005. Under the 2°C warming scenario RCP2.6, the rise is 60-80cm. In Maputo in southern Africa, for example, is it approximately 5cm higher by the end of the century in both warming scenarios (Schellnhuber et al., 2013). In contrast, Mediterranean sea levels on the North African coastline are projected to be lower than for the rest of the continent: 60-70 cm with 2°C warming and 90-100cm with 4°C warming (Schellnhuber et al., 2013).

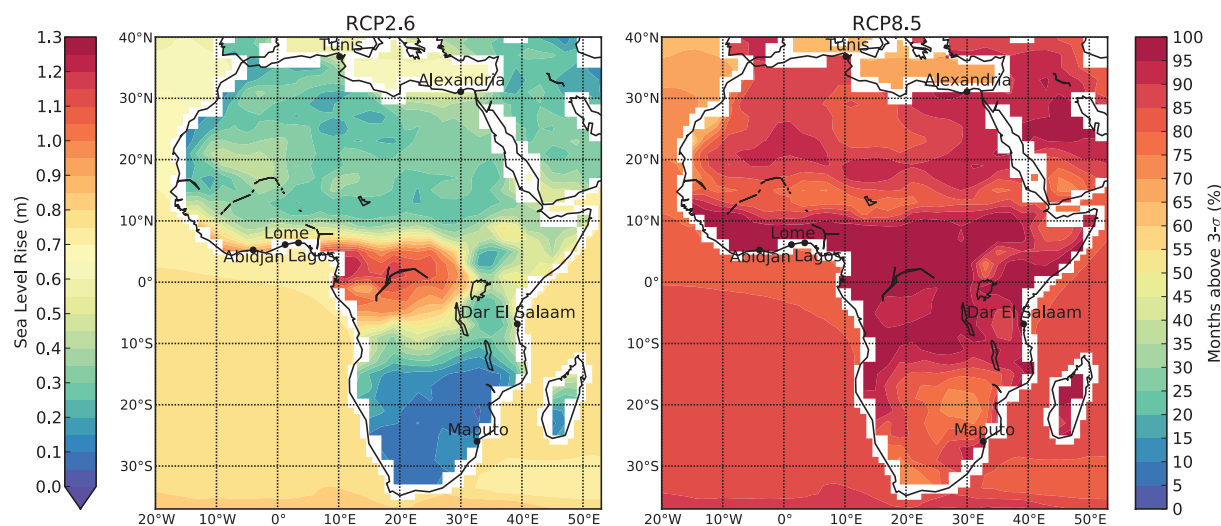


Figure 2.3 Projections for sea-level rise above present-day levels (ocean – left legend) and warming compared to present-day extremes (land – right legend) for 2100. With 2°C warming (left panel – RCP2.6 scenario) by 2100, sea-level rise is projected to be less than 80 cm (orange over oceans) and the likelihood that a summer month's heat is unprecedented in current (local) historical climate records is generally less than 50 percent (green/blue colors over land), with locally more extremes in western equatorial Africa. With 4°C warming (right panel – RCP8.5 scenario), sea-level rise is projected to be more than 100 cm (red over oceans) and the likelihood that a summer month's heat is locally unprecedented in current history is greater than 70 percent (orange/red colors over land). Locations particularly vulnerable to the impacts of sea-level rise mentioned in the text are indicated by black dots. Source: PIK (Schellnhuber et al., 2013)

2.2.2 Extremes / Catastrophic events

Coastal flooding and storm surges

In a 4°C world and assuming no adaptation, (Hinkel et al., 2011) find Egypt, Mozambique and Nigeria to be most affected by sea-level rise in terms of number of people at risk of flooding annually. However, Guinea-Bissau, Mozambique, and The Gambia would suffer the highest proportion – up to 10% – of the national population flooded.

Flooding associated with tropical cyclone induced storm surges is another impact of global climate change, which, in conjunction with sea-level rise, will place more people at risk of coastal flooding. (Neumann, Emanuel, Ravela, Ludwig, & Verly, 2013) project that in Maputo, Mozambique, for example, a medium sea-level rise scenario of 0.3m by 2050 (associated with close to 2°C warming globally by that time) could increase the frequency of a current 1-in-100-year storm surge event associated with 1.1m surges to once every 20 years. In 2050, sea-level rise in 2°C and 4°C warming scenarios is approximately the same, diverging rapidly afterwards. A 2011 study by Dasgupta et al considers the combined effects of a 10% intensification of storm surges in addition to 1m sea-level rise. Tunisia, Tanzania and Mozambique emerge as among the most exposed in the developing world (Dasgupta, Laplante, Murray, & Wheeler, 2011) in terms of overall exposure of a number of indicators: proportion of land area, GDP, urban land area, agricultural area and wetland exposed.

The analysis by (Hinkel et al., 2011) further considers potential economic damage associated with sea-level rise due to coastal flooding, forced migration, salinity intrusion, and loss of dry land. The African countries projected to experience the highest damage costs are Mozambique and Guinea-Bissau. Taking into account storm surges, (Dasgupta et al., 2011) find that the most economically important areas (accounting for more than 25% of GDP) that are prone to storm surges are located in Tunisia, Tanzania and Mozambique.

In a study by (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013), Abidjan in Cote d'Ivoire ranks highly in a global ranking of current exposure of cities in terms of average annual loss (AAL) as a percentage of GDP, with an AAL of 0.72% of GDP. On projections that assume 40cm sea-level rise by 2050 and take into account socio-economic change, subsidence, and adaptation (i.e. flood defences) to maintain present flood probability, this could rise to 1.03%, an increase of 44%. In Alexandria, Egypt, relative AAL is projected to increase from 0.09% of GDP at present to 0.25%. Importantly, these projections assume better flood defences due to adaptation efforts, which would maintain the frequency of flooding at current rates. This means that increased damage still projected is a result of the increased extent (not frequency) of flooding due to climate change, as well as population and economic growth.

Extreme heat events

Summer heat extremes greater than 3 standard deviations (hereafter: sigma) outside of historical variation³ (in other words, warming three times larger than the magnitude of normal variation experienced in today's climate) represent prolonged and high-impact heat waves. 3 sigma events are virtually absent from local climatology today and are here termed "highly unusual"; 5 sigma events are those that are historically unprecedented. Both are projected to become more frequent with climate change (Schellnhuber et al., 2012).

In a 4°C warming scenario, almost all (80-100%) boreal summer months (JJA) in North Africa are projected to experience heat events that are currently considered highly unusual (Figure 2.3 – land areas, left panel), by the end of the century. Approximately half of North African summer months could see heat events that are historically unprecedented (Schellnhuber et al., 2012). In Sub-Saharan Africa 60-100% of austral summer months (DJF) could be highly unusual (Schellnhuber et al., 2013). In tropical central Africa, currently unprecedented warm months are projected to become the new normal, occurring annually (Schellnhuber et al., 2012); this is in large part due to small historical variation in the equatorial belt.

With 2°C warming, the picture is very different. Highly unusual heat events are experienced in 60-80% of summer months only in parts of central Africa; in 40-60% of months in the Horn of Africa and North Africa; and in 0-30% of months in southern Africa. Unprecedented warm events remain largely unknown for Africa, except for tropical central Africa where they are projected to occur with 20-50% frequency.

³ Such events – termed "highly unusual" in this report – would have a theoretical rate of occurrence of once every 740 years. Another class of events assessed here – termed "unprecedented" – are 5-sigma events and would be virtually absent in historical climatology, with a theoretical return time of several million years

Drought

Droughts are expected to become increasingly likely in central and southern Africa (Schellnhuber et al., 2013). This is consistent with findings for southern Africa of significant soil moisture decreases by (Trenberth, 2010) and of a permanent state of severe to extreme drought in 2100 compared to 1980-1999 under scenario RCP4.5 according to the Palmer Drought Severity Index by (Dai, 2012). Dai 2012 also projects increased drought risk for

2.2.3 Ecosystems

Terrestrial ecosystems

(Scheiter & Higgins, 2009) show that increased atmospheric CO₂ concentrations, which benefit many trees more than grasses, could force shifts from grassland and savannah ecosystems to forest ecosystems. At CO₂ concentrations associated with 3.5°C of warming above pre-industrial levels they projected marked shifts in biomes whereby deserts are replaced by grasslands, grasslands by savannahs, and savannahs by forests. This shift has been simulated for East Africa by (Doherty, Sitch, Smith, Lewis, & Thornton, 2010). Such a conversion of savannah to forest can occur in less than 20-30 years (Bond & Parr, 2010).

Consistent with the findings of Higgins and Scheiter (2012) is evidence that woody savannah vegetation is “thickening” (Parr, Gray, & Bond, 2012). One potential consequence of this is woody plant encroachment, which can have implications for local ecology, agriculture and hydrology. Vegetation “thickening” could also increase the risk of wildfire due to increased fuel load (Adams, 2013). (Betts et al., 2013) find that levels of fire potential increase in central and southern Africa under 2°C warming and in all non-desert parts of Africa under 4°C warming, thereby serving to block the conversion of savannah to forest associated with elevated CO₂ concentrations. Increases in temperature and drought incidents can also cause tree mortality (as has been observed in the Sahel in recent decades (P. Gonzalez, Tucker, & Sy, 2012)). Changes in climatic conditions may therefore outweigh the potential benefits for trees of heightened CO₂ fertilization, ultimately favouring heat resistant grasses at the expense of forests (Bond and Parr 2010).

As climates change on the local level, biomes, i.e. large-scale climatological habitat zones, may occur, may shift, meaning that species need to migrate or disappear as one vegetation state is replaced by another. Most projections agree on a pole ward shift of vegetation and degradation of tropical biomes (e.g. (Bergengren, Waliser, & Yung, 2011); Betts et al 2013; Gonzalez et al 2010). Based on 20th century observations and 21st century projections, pole ward latitudinal biome shifts of up to 400 km are found to be possible in a 4°C world (Patrick Gonzalez, Neilson, Lenihan, & Drapek, 2010). Betts et al 2013 project a reduction in broadleaf tree cover in almost all equatorial forest areas of Africa by the end of the century due to combined climatic and human pressures.⁴

(Beaumont et al., 2011) show that the tropical and sub-tropical terrestrial eco-regions in central, southern and East Africa ranked among the G200 (a list of ecosystems of “exceptional biodiversity”) may experience temperature shifts of 3 or 4 sigma under the SRES A2 scenario. Significant shifts in climatic conditions could cause the disappearance of some existing biomes and the emergence of novel climates (Williams, Jackson, & Kutzbach, 2007). The climates in Africa found to be a risk of disappearing are concentrated in tropical mountains and the southernmost regions closest to the South Pole. They include the African Rift Mountains, the Zambian and Angolan highlands and the Cape Province of South Africa. Novel climates – that is, currently unprecedented climatic conditions – are projected for the western Sahara and low-lying portions of East Africa by the end of the century (Williams et al., 2007).

Faced with climatic change on the local level, there is a risk that ecoregions will experience a loss of biodiversity, as species may be unable to migrate to keep pace with shifting suitable climatic conditions. As savannahs are replaced by woody vegetation in South Africa, Parr, Gray & Bond 2012 point to the risk of potential loss of many specialist plant species. A study by (McClellan et al., 2005) found that of 5197 African plant species studied, 81-97% were projected to experience range size reductions or shifts and 25-42% could lose all suitable range by 2085 under a relatively conservative warming scenario reaching 2°C by 2100.

Freshwater ecosystems

Freshwater ecosystems are expected to be affected by climate change due to increased temperatures and altered river flow. (Beaumont et al., 2011) identified freshwater ecosystems covering a significant portion of central Africa, coastal areas

⁴ Note that most of the other studies cited here consider the climate change impacts on ecosystems independent of human influences. However, human pressures, which include urban expansion, deforestation and the introduction of alien species among others, will interact with climate change impacts in complex ways to affect ecosystems.

of West Africa and Madagascar as at risk of significant temperature shifts at 3°C warming globally. Van Vliet et al project both decreased low flow and large increases in mean water temperature in southern and northern African rivers under 4°C warming by the 2080s, with the affected area smaller under 2°C, and increased seasonality of river flow particularly for the Zambezi river catchment area (lower in the dry season and higher in the wet season).

Fish productivity in lakes is expected to decline with increased water temperatures, high levels of evaporation and decreased nutrient concentration as a result of reduced inflow. The deep African lakes of East Africa could be particularly vulnerable (Ndebele-Murisa, Musil, & Raitt, 2010). With lakes such as Chilwa, Kariba, Malawi, Tanganyika and Victoria contributing more than 60% of dietary protein consumed in bordering rural communities (Ndebele-Murisa et al 2010), climate change impacts on freshwater fisheries will have serious implications for human populations.

Marine ecosystems

Marine ecosystems, including coral reefs and the fisheries that depend on them, are expected to be among the natural systems affected the earliest by climatic changes (Drinkwater et al., 2010); (Brander, 2007). Coral reefs flourish in a relatively narrow range of temperature tolerance and are hence highly vulnerable to sea-surface temperature increases; together with the effects of ocean acidification, this exposes coral reefs to more severe thermal stress, resulting in bleaching. Rising sea surface temperatures have already led to major, damaging coral bleaching events in the last few decades. Projections indicate that coral reefs off the coasts of Africa are very likely to experience thermal stress by the year 2050 at warming levels of 1.5°C–2°C above pre-industrial levels, with a severe coral-bleaching event once, or more, every ten years. Most coral reefs are projected to be extinct long before 4°C warming is reached, due to severe coral-bleaching events annually chemical stress due to ocean acidification, with the loss of associated marine fisheries, tourism, and coastal protection against sea-level rise and storm surges (Meissner, Lippmann, & Sen Gupta, 2012).

In a study of global fish species distribution and patterns of catch yield potential (William W. L. Cheung et al., 2010) find a pole ward movement of species under 2°C global temperature rise, with an increase in catch potential in the high latitudes and a decrease in tropical regions. Their study shows that yield potential could in fact increase by 16% off the eastern and south-eastern coasts of Sub-Saharan Africa (Madagascar, Mozambique, Tanzania, and Kenya), but that closer to the coastline the direction of change is reversed and yield potential changes by -16% and -5%. Significant adverse changes in maximum catch potential are projected of -16 to -5% for the Red Sea, as well as off the coast for Namibia, -31 to -15% for Cameroon and Gabon, and up to -50% along the West African coast from Gabon up to Mauritania and along the Mediterranean coast (Cheung et al. 2010).

The study by Cheung et al 2010 takes into account changes in sea-surface temperatures, primary production, salinity, and coastal upwelling zones. A subsequent study (W. W. L. Cheung, Dunne, Sermiento, & Pauly, 2011) added ocean acidification, oxygen availability and phytoplankton community structure to these factors. They find that acidification and reduced oxygen content lowered the estimated catch potentials by 20–30% relative to the results of the previous study and other simulations not considering these factors.

Diminished catch potential will have a significant impact on human communities, particularly in regions where fish accounts for a large proportion of animal protein consumed. In a study of projected changes to fishery yields in West Africa by 2055 (under approx. 2°C warming globally), (Lam, Cheung, Swartz, & Sumaila, 2012) quantitative studies on the potential impact of climate change on fisheries and its subsequent impact on human well-being in West Africa are still scarce. This paper aims to assess the potential impacts of climate change on fisheries and their effects on the economics, food and nutritional security in West Africa. We use a dynamic bioclimatic envelope model to project future distribution and maximum fisheries catch potential of fish and invertebrates in West African waters. Our projections show that climate change may lead to substantial reduction in marine fish production and decline in fish protein supply in this region by the 2050s under the Special Report on Emission Scenarios (SRES compare projected changes in catch potential with projected protein demand (based on population growth, excluding dietary shifts). They show that in 2055 Ghana and Sierra Leone are projected to experience decreases of 7.6% and 7.0%, respectively, from the amount of protein consumed in 2000.

2.2.4 Water Resources

Through changes to the hydrological cycle, climate change is expected to affect the timing, distribution and quantity of water resources (Goulden, Conway, & Persechini, 2009). It is expected that climate change will cause many African countries that are already facing water shortages to experience increased water stress in the coming decades (Schellnhuber et al., 2012).

Levels of surface runoff

(Fung, Lopez, & New, 2011) find decreases in runoff of 60-80% for both 2°C and 4°C warming for much of Sub-Saharan Africa for a warming of 4°C by 2100 above 1961-1990 levels. There is broad consensus among projections of future water availability that southern Africa will become drier. Decreased river discharge is projected for southern Africa ((Xenopoulos et al., 2005) reduce freshwater biodiversity. We combined two scenarios from the Intergovernmental Panel for Climate Change with a global hydrological model to build global scenarios of future losses in river discharge from climate change and increased water withdrawal. Applying these results to known relationships between fish species and discharge, we build scenarios of losses (at equilibrium; (P Döll & Zhang, 2010); (van Vliet et al., 2013); (Thieme, Lehner, Abell, & Matthews, 2010)), and parts of North Africa and West Africa (Xenopoulos et al 2005; (P Döll & Zhang, 2010); Thieme et al 2010), while mean annual discharge is projected to increase for large parts of tropical monsoon regions (Van Vliet et al 2013; Betts et al 2013).

(Schewe et al., 2013) find decreases in annual runoff in southern Africa of 30-50%, particularly for Namibia, east Angola, western South Africa, Madagascar and Zambia, under warming of 2.7°C by 2060-80. These impacts are greater by up to a factor of two for warming of approximately 3.5°C. (Hagemann et al., 2013) project decreases of more than 10% in available water resources in the Okavango and Limpopo catchments in southern Africa at about 4°C warming globally by the 2080s (compared to the 1980s).

In contrast to regional climate models (see 2.1) global climate models project an increase in precipitation over East Africa and therefore in available water resources, although large uncertainties apply. Schewe et al 2013 find significant model consensus on an increase of annual runoff of approximately 50% in East Africa, particularly southern Somalia, Kenya and southern Ethiopia with 2.7°C warming. They find a decrease in runoff over almost all of West Africa.

In the Maghreb (North Africa west of Egypt), water availability is projected to decrease, particularly in the coastal areas. For 2050 under about 2°C warming globally, Milano et al 2013 project decreases in mean annual freshwater availability of greater than 50% in coastal catchment areas in Morocco and Algeria, but unchanged or slightly increased availability in parts of Tunisia and Libya. Consistent with this is a decrease in river low flow by 2071-2100 of greater than 25% in coastal Morocco and Algeria projected by Van Vliet et al (2013) compared to 1971-2000.

The picture of water availability in the Nile River Basin (which extends from Egypt to the highlands of East Africa) is complex, with the direction of precipitation change varying between the catchment areas of the Nile's tributaries (Beyene, Lettenmaier, & Kabat, 2010). Fung et al 2011 find that with 2°C warming mean annual surface runoff in the Nile basin increases by approximately 20% compared to a 1961-1990 baseline and this effect is approximately doubled with 4°C warming. However, the seasonality of runoff increases so that what may appear to be a beneficial increase in water availability could in fact simply leave unchanged the current pattern of flooding in the high-flow season and water stress in the low-flow season.

Beyene et al 2010 simulate streamflow at the gauging station at High Aswan Dam. Under about 3.5°C warming globally, changes in mean annual streamflow entering High Aswan Dam amount to between -38% and 12% for the period 2070-2099.

Groundwater availability

A study by (Petra Döll, 2009) for the period 2041-79 at about 2°C warming globally projects that groundwater recharge rates decrease by 30-70% in North Africa and south-western Africa compared to the 1961-90 period. In contrast the recharge rate could increase in some parts of eastern southern African and East Africa by 30%. However, due to the many factors involved, such as topography, vegetation and soil or rock type, the recharge of groundwater by precipitation is complex and projections are relatively unreliable. African groundwater supply requires 3-10mm of precipitation each year to be adequately recharged and is considered relatively resilient to climate change impacts (Kundzewicz and Doll 2009). (MacDonald, Calow, MacDonald, Darling, & Dochartaigh, 2009) claim that climate change is unlikely to result in a 'catastrophic failure' of improved groundwater sources, but that increased intensity of rainfall could cause contamination of shallow sources, thereby contributing to water insecurity.

Per capita water availability

Measuring the availability of water resources in relation to the number of people dependent on them yields an arguably more meaningful picture of the impacts of climate change on Africa's populations. Where population growth and economic development is expected to occur, water availability will be determined by demand as well as by climatic factors.

Water withdrawals on the southern edge of the Mediterranean are expected to double by 2050 under a business-as-usual water-use scenario (Milano et al 2013). Combined with climate change, this pressure on water resources is projected to place catchment areas of Morocco, Algeria, Tunisia and Libya at very high levels of water stress, meaning in this study that the ratio of annual water withdrawals to annual renewable water resources is greater than 80% by 2050.

(Vorosmarty et al., 2010) and (Goulden et al 2009) show that large parts of Africa currently have medium to high threats of blue water (rivers, streams, lakes, reservoirs and aquifers) scarcity (less than 1,000 m³ per capita per year – UNDP 2006). Apart from North Africa and south-eastern Africa, water security threats appear to be particularly high along the Guinea coast and East Africa, which is consistent with the claim by Goulden et al 2009 that the Nile and Volta basins are approaching situations of water stress (less than 1700m³ per person per year) (Goulden et al 2009). Fung et al 2010 project increased water stress in the Nile River basin under all population and climate scenarios. They also project water stress to increase over the rest of Africa.

Changes to water availability for agriculture

The projections of water availability in previous sections refer to “blue water”. “Green water” refers to the precipitation that infiltrates the soil and enables agriculture where irrigation is not in use. A 2011 study by Gerten provides projections of both blue and green water availability for the period 2070-2099 (compared to a 1971-2000 baseline) under warming of 3.5°C above pre-industrial levels by that time, and taking into account population growth. For all of Africa, the likelihood that total blue and green water (BWGW) availability will decline by more than 10% is found to be highly likely (90-100% probability).

Gerten et al then compare total BWGW available for both rainfed and irrigated agriculture with the amount required to produce a standard diet for the population, assuming that the CO₂ fertilization effect will actually reduce the amount of water required to achieve this. Countries are considered water scarce when BWGW availability falls below the per capita amount required. Gerten et al find that there is a very high probability (90-100%) that by the 2080s countries in North Africa, much of East and West Africa and Angola will be water scarce. Although water availability over most of southern Africa is projected to decrease, this region is unlikely (0-10%) to become newly water scarce, as population in currently dry areas is already limited and projected population growth is lower than for other parts of Africa. In other words, a lower likelihood to become water scarce reflects lower agricultural demand for water and does not refer to absolute water availability.

In their study of water availability in the Nile River basin, Beyene et al (2010) project a roughly 15% decline in the mean annual irrigation releases from High Aswan Dam, suggesting that Egypt could experience a reduction of the equivalent of 457 000 ha of currently irrigable land by the end of the century.

2.2.5 Agriculture

Crops

Climate change is expected to impact crop production in Africa through changes in temperature and the quantity and temporal distribution of water supply. With the main exception of Egypt, the vast majority of agriculture in Africa is rainfed, making it particularly vulnerable to changes in precipitation patterns. While many of the projected effects of climate change on agriculture are negative, it is possible that productivity could increase in some areas due to more favourable climatic conditions. There is some suggestion that this may temporarily be the case for Egypt as water availability in the Nile River Basin potentially increases in the coming decades (Schilling, Freier, Hertig, & Scheffran, 2012), before a decline as warming progresses (Beyene et al 2010).

A relatively immediate way in which crop production may be affected by climate change is through elevated temperatures. The optimal temperature for wheat is between approximately 15 and 20°C, depending on variety, and as (Liu et al., 2008) observe, annual average temperatures during the crop growing period in Sub-Saharan Africa already exceed this range. Another very widely produced crop in Africa, maize, is particularly sensitive to temperatures above 30°C during the growing season. According to (Lobell, Schlenker, & Costa-Roberts, 2011), yields are diminished by 1% for each day a maize crop is subjected to temperatures above this threshold. Similar thresholds have been observed to exist for soybeans and cotton (Schlenker & Roberts, 2009).

Local climatic changes can alter the length of the crop-growing season, defined as the period in which temperature and

soil moisture are conducive to crop development. Based on an ensemble of 14 GCMs, (Philip K Thornton, Jones, Ericksen, & Challinor, 2011) project that the length of the growing period could be reduced by more than 20% across most of Sub-Saharan Africa by the 2090s (with a global-mean warming of 5.4°C above pre-industrial levels). The season failure rate is also projected by Thornton et al to increase (2011) – as frequently as once every two years in southern Africa, without adaptation.

The areas that are appropriate for any given crop are also expected to shift as local climates change. Thornton et al project that approximately 5% of Sub-Saharan Africa where mixed crop and livestock production currently occurs could undergo a shift to exclusively rangeland, where cropping is no longer viable. (Burke, Lobell, & Guarino, 2009) identify a risk that the majority of African countries will feature novel crop climates in at least half of their current crop area by the 2050s under about 2°C warming globally. For maize, millet and sorghum, Burke et al. (2009) estimate that the growing season temperature for any given maize crop area in Africa will overlap with current cropping areas on average by only 12-15 percent by 2050 (2.1°C), and 2-3 percent by 2075 (3°C), implying that if global warming exceeds 3°C above pre-industrial, current cultivars may no longer be suitable across virtually all present-day cropping areas in Africa.

A large number of studies investigate the effect of climatic changes on crop yield across Africa. A review by (Knox, Hess, Daccache, & Wheeler, 2012) of publications containing data on crop productivity in Africa points to mean yield changes by the 2050s of –17% for wheat, –5% for maize, –15% for sorghum, and –10% for millet. The overall findings of a review of 16 studies on West Africa by (Roudier, Sultan, Quirion, & Berg, 2011) are broadly consistent with those of Knox et al, pointing to a median 11% loss by the 2080s in the sub-region.

A global study containing probabilistic projections of climate change impacts on crop production in 2030, carried out by (Lobell et al., 2008), ranks southern Africa as one of the most affected regions considered. Here maize production is projected to decline by 20-35% and wheat production by 10-20% compared to 1998-2002 average yields. (Nelson et al., 2010) find that crop production in Africa could increase by 2050 under a global mean warming of 1.8-2°C, but that in light of population growth, per capita crop production would be reduced.

One factor that can significantly affect crop production, and one which has not yet been mentioned in this section, is extreme events such as floods. These have the potential to unexpectedly destroy harvests or infrastructure that is critical to the agriculture sector, but it is a risk about which not enough data is currently available.

Livestock

Relatively few quantitative studies have investigated the complex effect of climatic changes on livestock production, which is expected to occur via changes in feed quality and availability, water availability, and increased incidence of disease and heat stress (P. K. Thornton, van de Steeg, Notenbaert, & Herrero, 2009). Those parts of the African continent that are projected to be at greater risk of drought, including northern and southern Africa, will be placed at greater risk of livestock loss (P. K. Thornton et al., 2009).

Declines in rainfall in the Sahelian Ferlo region of northern Senegal have been observed to lead to reduced optimal stocking density. A 30% reduction in the latter has been projected to occur following a 15% decrease in rainfall along with a 20% increase in rainfall variability (Hein, Metzger, & Leemans, 2009). In a study of the Sikasso region of Mali, an increase of temperature of 1-2.5°C by the 2030s compared to the 1960-1991 period is found to alter the maintenance requirements of livestock as well as directly impact the health of the animals via heat stress (Butt, McCarl, Angerer, Dyke, & Stuth, 2005). All the livestock considered in the study – cattle, sheep and goats – show signs of loss of appetite and subsequent diminished feed consumption. This has the greatest impact on cattle, and their rate of weight gain declines to -13.6 to 15.7%.

2.2.6 Other Market Sectors

Fisheries

The vulnerability of national economies to climate change impacts on freshwater and marine fisheries is studied by (Allison et al., 2009). The most vulnerable countries in Africa⁵ are found to be among those in West and Central Africa, as well as Mozambique, Tanzania, Morocco and Algeria. There is very little difference in the countries identified as vulnerable across scenarios.

⁵ Here vulnerability is calculated by taking into account exposure to climate variables, the dependence of national economies on the fishery sector (represented by an indicator comprised of fisheries production and the contribution of fisheries to employment, export income and dietary protein), and adaptive capacity.

(Lam et al., 2012) quantitative studies on the potential impact of climate change on fisheries and its subsequent impact on human well-being in West Africa are still scarce. This paper aims to assess the potential impacts of climate change on fisheries and their effects on the economics, food and nutritional security in West Africa. We use a dynamic bioclimatic envelope model to project future distribution and maximum fisheries catch potential of fish and invertebrates in West African waters. Our projections show that climate change may lead to substantial reduction in marine fish production and decline in fish protein supply in this region by the 2050s under the Special Report on Emission Scenarios (SRES give an indication of the magnitude of economic losses that could result from reduced catch in West Africa's marine fisheries by 2050 under about 2°C warming globally. They project economic losses of 21% of annual total landed value compared to 2000 (from \$732 million currently to \$577 million, using constant 2000 dollars) and a 50% decline in fisheries-related jobs. Côte d'Ivoire, Ghana, and Togo, with up to 40% declines, are projected to suffer the greatest impacts on their landed values.

Tourism

Climate change is expected to affect the tourism sector of Africa through diminished numbers of tourists, where would-be visitors could potentially be deterred by a wide range of climate change related factors. These factors include hotter and drier conditions, extreme weather events such as cyclones, damage to sites of natural beauty, outbreaks of disease and heightened security risks. For example, the tourism industry in Morocco and Tunisia is expected to be significantly affected simply by increases in temperature that could render summertime and even the off-peak seasons less pleasant (Deutsche Bank Research, 2008). Globally, a shift in tourism activity towards higher latitudes and altitudes is expected (Simpson, Gössling, Scott, Hall, & Gladin, 2008). Revenue generated from tourism will be directly affected by damage to infrastructure and changes in the length and quality of climate-dependent tourism seasons (Steyn & Spencer, 2012).

The loss of biodiversity and important species in nature parks and reserves as result of climate change impacts could affect their attractiveness as tourist destinations. One such attraction is Mount Kilimajaro in Tanzania – one of the nation's main tourism attractions. It is suffering severe glacial melt and, along with the other glaciers of East Africa, is expected to disappear altogether in the coming decades (UNEP Global Environmental Alert Service, 2013).

The Nile Delta of Egypt, which is particularly vulnerable to inundation and saltwater intrusion associated with sea level rise, provides an example of the potential impact of sea-level rise on tourism (Michel & Pandya, 2010). Rising sea levels are expected to destroy parts of the protective offshore sand belt, which could damage recreational tourism and beach facilities, in addition to inundating coastal freshwater lagoons and salinating groundwater resources (Batisha, 2012). In Alexandria, the area of land associated with tourism purposes that is below sea level would increase from the current level of 28% to 62% with a sea-level rise of 1m, and valuable cultural sites could be placed at risk by storm surges (Michel & Pandya 2010).

Energy

Some African countries, including Zambia, Namibia and Mozambique, rely almost exclusively on hydroelectric sources for their electricity production. The rest of the continent rely primarily on thermo-electrical sources such as coal, oil or gas for electricity production (World Bank, 2013). As levels of river run-off and the incidence of heat extremes are altered by climate change, hydroelectric dams and the cooling systems of thermoelectric power plants may experience production disruptions, causing power outages (Förster & Lilliestam, 2009).

2.2.7 Health

Changes in climatic conditions, including temperature and precipitation patterns, as well as the incidence of extreme events such as droughts and heat waves, have the potential to undermine human health in Africa. Extreme weather events such as flooding and storm surges can also cause injury and fatality. Rates of undernutrition and infectious disease, already relatively high in Africa, could increase in the coming decades compared to a scenario without climate change.

(Lloyd, Kovats, & Chalabi, 2011) project that the rate of undernourishment in the Sub-Saharan African population would increase by 25-90% with a warming of 1.2-1.9°C by 2050 compared to the present. Undernutrition can place people at risk of other health conditions including child stunting, which in turn results in reduced cognitive development and poor health into adulthood. According to (Lloyd et al., 2011), the proportion of moderately stunted children ranges between 16-22% in the 2010 baseline scenario and would remain at approximately this level in a future scenario without climate change. With climate change, this rate is projected to increase by 9% above 2010 levels. The proportion of severely stunted children, which accounts for 12-20% at present, is projected to decrease by 40% without climate change and by only 10% with climate change.

The distribution of vector-borne diseases such as malaria and dengue fever and water-borne diseases such as cholera and dysentery is already being affected by local environmental changes across Africa. Flooding can result in outbreaks of cholera, for example, and droughts have been associated with diarrhoea, scabies, conjunctivitis and trachoma (Patz, Olson, Uejo, & Gibbs, 2008). More gradual shifts in temperature and rainfall may also have a significant effect on the geographic range of many diseases. Malaria is expected to disappear from some areas and spread into others that were previously unsuitable to support the pathogens. The former includes the Sahel where the epidemic belt is projected to move southward by 1-2° with a warming of 1.7°C by the period 2031-50 (Caminade et al., 2011). The latter include the highlands of Ethiopia, Kenya, Rwanda and Burundi where the frequency of epidemics is already reported to be increasing (Pascual, Ahumada, Chaves, Rodo, & Bouma, 2006).

2.2.8 Cities

The residents of cities, particularly the poor residents of informal settlements who account for a large proportion of Africa's urban population, are expected to be particularly vulnerable to the impacts of climate change. Cities are in many cases exposed to sea-level rise, tropical cyclones and other heavy precipitation events, extreme heat events and drought (UN Habitat, 2011). Projections of the risk of coastal flooding associated with sea-level rise and storm surges were discussed above in section 2.2.2. Exposure to flooding (both coastal or inland following heavy precipitation) and storm damage is high in settlements where housing tends to be of poor quality and is easily damaged or destroyed. Informal settlements are often situated in precarious locations such as floodplains or steep slopes that may be prone to landslides (Douglas et al., 2008). Cities tend to experience higher air and surface temperatures compared to surrounding areas due to the urban heat island effect, and this can affect human health through increased incidence of heat stress (UN Habitat, 2011). Other health risks that may be pronounced in cities are those associated with flooding, as flooding can contaminate drinking water supplies and create conditions conducive to pathogens (McMichael, Barnett, & McMichael, 2012).

Sea-level rise and the extreme events outlined here can additionally disrupt the provision of basic services, such as water and energy supplies and transport infrastructure, even in areas less directly impacted (UN Habitat, 2011). Economic activity and poverty levels can also be affected by these climate risks, and in some cases urban populations may be impacted in particular ways even where the event is geographically removed. For example, (Ahmed, Diffenbaugh, & Hertel, 2009) identify urban wage earning populations as particularly susceptible to increased poverty brought about by elevated food prices following disruptions to agricultural production in rural areas.

Climatic risk factors in rural areas may exacerbate an already significant urbanisation trend in Africa, potentially placing more people in vulnerable conditions as settlements become more crowded and resources are stretched (Smit & Parnell, 2012). Hence, more and more people could find themselves in the increasingly vulnerable urban conditions described here.



03 Adaptation Options and Measures

The capacity of African communities to cope with the effects of climate change on different economic sectors and human activities is expected to be significantly challenged, and potentially overcome, by the magnitude of the impacts. Climate change could, for example, drive a growing number of people into poverty traps (Carter, Little, Mogues, & Negatu, 2007). To reduce the magnitude of the impacts and their repercussions for African livelihoods, adaption measures at different levels, from households to national and regional levels, are being planned and implemented.

This section illustrates some of the sectoral adaptation options and measures proposed in the literature and being carried out in some of the most vulnerable African countries, like the continent's LDCs.

3.1 Access to water

In a number of African countries, access to safe drinking water is low with great disparities between rural and urban areas. The latter tend to benefit from better connections to piped water infrastructure. To ensure reliable access to safe water in a context of climate change, (Kundzewicz et al., 2007) identify a set of measures, including increased but sustainable use of groundwater resources, desalinisation of seawater and increased water storage in reservoirs. (Pandey, Gupta, & Anderson, 2003) also see rainwater harvesting as a potential adaptation measure. Looking at climatological and archaeological data throughout human history, the authors observe that rainwater harvesting has been effectively implemented in response to abrupt climate fluctuations.

Rainwater catchment and storage projects have been put forward by some LDCs, for example Sudan⁶ and Sierra Leone⁷, in their National Adaptation Programme of Actions (NAPAs). For the project in Sierra Leone, the government requested \$2.8 million for a three-year project that includes sensitisation of the population to the benefits of rainwater catchment and storage, demonstration of the technology through a pilot project and installation of rainwater harvesting facility in key institutions (hospitals). For a three-year project in Sudan, the government estimated that \$0.75 million are necessary to construct water-harvesting facilities. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

3.2 Agricultural food production

In the period 2010-2012, approximately 239 million people were undernourished in Africa – about 23% of the continent's total population (FAO, 2012). The climate change related biophysical stressors outlined in section 2.2 are projected to exacerbate the population's existing vulnerabilities by reducing crop yield and production. Due to the importance of the issue and its implications for food security, human and economic development, a significant amount of research has been conducted on adaptation in the agricultural sector (see, for example, Pradeep Kurukulasuriya & Rosenthal, 2003 for a review of adaptation options).

(P. Kurukulasuriya et al., 2006) observe that irrigation as an adaptation measure has a positive effect on farming households' revenues. After surveying about 9,000 farmers in 11 African countries, they observe that irrigation increases agricultural incomes despite moderate temperature increase. (Smith & Olesen, 2010) cost effective greenhouse gas (GHG) have identified agricultural adaptation options that could also have a positive impact on the mitigation of GHG emissions, such as measures that reduce soil erosion or increase the diversity of crop rotations. In the Economics of Adaptation to Climate Change (EACC) studies, the World Bank also identifies as options irrigation, improvement in water storage capacity and research and development to discover, for example, more drought-resistant species.

⁶ Sudan NAPA Project Profile http://unfccc.int/files/adaptation/napas/application/pdf/33_sud_pp.pdf

⁷ Sierra Leone NAPA Project Profile http://unfccc.int/files/adaptation/napas/application/pdf/32_sierrall_pp.pdf

Following these measures proposed by scholars, the governments of Cape Verde⁸ and Chad⁹ have put forward agricultural project proposals for the modernisation and diversification of agricultural production, in the case of Cape Verde, and the capture of surface water for agriculture and provision of food for livestock, in the case of Chad. For a three-year project, the government of Chad estimated the needs for this specific area at \$1.8 million. The project includes the development of irrigation systems and reforestation to protect surface water systems. Cape Verde requested \$1.5 million for a five-year project that includes capacity building for smallholders and research and development activities for the protection of local ecosystems and agriculture. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

3.3 Marine and freshwater fisheries

Marine and freshwater fisheries are an affordable and easily accessible source of protein in African countries. Sustaining affordable access to fish in the context of climate change will necessitate the adoption of measures aimed at protecting particular fish species or relieving fishing pressure on specific species or areas (Cinner et al., 2012). The survival of freshwater fish species, for example, can be aided by creating thermal refugia such as deep ponds or reducing freshwater abstraction from rivers, lakes and ponds (Wilby & et al, 2010). A study by (Merino et al., 2012) shows that the global population's demand for fish could be sustained through 2050 in a scenario of 2°C warming by that time, by increasing aquacultural production and supporting the sustainable management of marine fish stocks.

Developing aquaculture as an adaption option is a measure put forward by the government of Gambia in its NAPA¹⁰. One of the priorities identified is to increase fish production through aquaculture and the conservation of post-harvest fishery products. The objective of the three-year fisheries project is to develop pilot aquaculture farms in Gambia for a total amount of \$.3 million. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

3.4 Tourism

In recent years, tourism has become an increasingly significant industry in Africa, generating revenue and jobs and contributing to infrastructure development (World Travel and Tourism Council, 2013). This promising growth of the sector could, however, be disrupted by climate change, as outlined in section 2.2.vi (Phillips & Jones, 2006; Scott, Gössling, & Hall, 2012; Turner, Vu, & Witt, 2012). African countries that are particularly vulnerable to the impacts of climate change on tourism, as a significant share of national revenue depends on the sector, include Mauritius, Cape Verde and Kenya.

Compared to other sectors, the availability of literature on adaptation in the tourism sector is limited. In 2008, the World Tourism Organisation (UNWTO) in collaboration with the United Nations Environment Programme (UNEP) reviewed potential adaptation options for the sector and different types of tourist destinations (mountains, islands, etc.). In the report (UNWTO, 2008), they recommend scientific monitoring programmes to assess the effects of climatic changes on biodiversity in vulnerable areas, as well as the designation of protected areas for threatened species.

The tourism sector is not among the highest adaptation priorities of the LDCs. According to the Least Developed Countries Fund (the fund financing the implementation of the NAPA), tourism represents less than 2% of the NAPA project profiles. One of the few projects focused on the tourism sector is the proposal by the government of Lesotho¹¹ to strengthen and stabilize ecotourism based rural livelihoods. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

3.5 Health

Many of the biophysical stressors associated with climate change will have direct and indirect detrimental effects on human health, as discussed in section 2.2.vii. These effects have increasingly been studied and there now exists a remarkable amount of literature on adaptation to climate change in the health sector.

The World Health Organisation has reviewed potential measures and developed a methodology to assess associated costs (World Health Organization, 2013). For example, WHO pinpoints the need for the development of early-warning systems for floods, droughts or fires to help populations anticipate and prepare for the occurrence of extreme events. WHO also advocates for better regulation to control the spread of water- and vector-borne diseases, while (McMichael & Lindgren,

8 Cape Verde NAPA Project Profile http://unfccc.int/files/adaptation/napas/application/pdf/07_cape_pp.pdf

9 Chad NAPA <http://unfccc.int/resource/docs/napa/tcd01.pdf>

10 Gambia NAPA Project Profile http://unfccc.int/files/adaptation/napas/application/pdf/14_gam_pp.pdf

11 Lesotho NAPA <http://unfccc.int/resource/docs/napa/lso01.pdf>

2011) identify the need for the widened geographic range of infectious disease surveillance programmes to improve prevention care services and public health services.

Both Togo¹² and the Central African Republic's¹³ NAPAs have project profiles focusing on the prevention of the transmission of water- and vector-borne diseases in rural areas. These projects include capacity building and sensitisation of local communities to the use of mosquito nets to prevent the spread of mosquito-borne diseases such as malaria and dengue fever. The total costs of the three-year projects are \$2 million and \$0.5 million, respectively. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

3.6 Access to energy

Access to reliable sources of energy is critical to human and economic development. Several authors and studies (Bolch et al., 2012; Förster & Lilliestam, 2009; Koch & Vögele, 2009; van Vliet et al., 2012) show that climate change associated stressors, such as increased frequency and intensity of droughts, increased rainfall seasonality and wet extremes, are projected to affect hydropower and thermoelectricity production. Despite World Bank's guide on adaptation in cities (Willmott, Le Courtois, Baker Gallegos, & Datta, 2011), which addresses adaptation to climate change in the power generation sector, studies specifically addressing this matter are scarce. To mitigate the impacts of climate change on the energy sector, there is a need to simultaneously address both supply and demand. In terms of ensuring supply of energy, investment in renewable sources, which do not depend on hydropower and water-cooling systems –thereby avoiding exposure to climatic changes –, is necessary (see for example Willmott, Le Courtois, Baker Gallegos, & Datta, 2011).

On the demand side, the adoption of more energy efficient building codes is also proposed as an adaptation measure in order to reduce pressure on electricity supply and therefore reduce the risk of power outages (Vine, 2011).

Adapting the energy sector to climate change represents only 2% of the project profiles put forward by the LDCs. Benin¹⁴ and Lesotho have proposed projects with the objective of promoting wind, solar and biogas energy as a supplement to hydropower and other existing sources.

3.7 Cities

About 40% of the African population resided in urban areas in 2011. It is projected that by 2035, more than 50% (or about 860 million people) of the population of the continent will live in cities (United Nations Department of Economic and Social Affairs, 2012). Cities are expected to be locations where many climate change impacts may collide and simultaneously be felt directly or indirectly.

In 2011 the World Bank published a "Guide to Climate Change Adaptation in Cities" in which adaptation options for different urban activities are reviewed. As one of the major threats to cities induced by climate change is coastal flooding, protection measures through coastal zone management including measures such as seawalls, dykes, wave breakers construction and zoning or urban planning (Willmott et al., 2011). The development of city-level food storage capacity and urban agriculture is recommended in order to enhance food security. Air-conditioning¹⁵ and better insulated and more energy efficient buildings are also recognized as potential adaptation measures to mitigate the impacts of heat extremes (Hunt & Watkiss, 2010).

Zambia¹⁶ and Liberia¹⁷ have included urban adaptation measures in their NAPAs. To strengthen coastal protection in the cities of Buchanan and Monrovia, the government of Liberia proposed a project of \$60 million and three-year duration that consists of the construction of a groyne system in Monrovia and a breakwater system in Buchanan. The construction of this infrastructure will contribute to the protection of the shore from coastal erosion and its potential repercussions for social and economic activity in coastal areas. The government of Zambia decided to allocate \$2 million to a project, which aims to decrease the spread of water-borne diseases in cities due to poor sanitation facilities. By improving the design and drainage technology of sanitation facilities, the proponents aim to reduce the risk of water-borne diseases in the aftermath of climate change related extreme weather events. The number of beneficiaries and the exact scale of the projects are not expressed in the project profile.

12 Togo NAPA <http://unfccc.int/resource/docs/napa/tgo01f.pdf>

13 Central African Republic NAPA <http://unfccc.int/resource/docs/napa/caf01f.pdf>

14 Benin NAPA project profile http://unfccc.int/files/adaptation/napas/application/pdf/02_ben_pp.pdf

15 Authors recognize that the multiplication of air-conditioning systems in African cities is not an optimal solution as it will increase energy demand and therefore GHG emissions. Furthermore, in rural areas, low energy access may not allow the development of air-conditioning systems. In this regard, more energy efficient and insulated buildings are seen as more appropriate to the African context.

16 Zambia NAPA project profile http://unfccc.int/files/adaptation/napas/application/pdf/38_zam_pp.pdf

17 Liberia NAPA project profile http://unfccc.int/files/adaptation/napas/application/pdf/20_libe_pp.pdf

04 Adaptation Costs

The process of estimating adaptation costs is complex and involves many uncertainties. Nevertheless, several studies have projected the costs of adaptation measures such as those listed in the previous section (Stern 2006; Oxfam 2007; UNDP 2007; UNFCCC 2007; de Bruin et al. 2009; Hof et al. 2010; World Bank 2010b). These studies differ in time period, scope, and methodology. Some studies focus on current adaptation costs, while others project adaptation costs until the end of the century; some studies look at investment flows, while others look at welfare effects; some studies project adaptation costs for developing regions or the world as a whole, while others project costs for specific regions.

In general, studies that focus on short-term adaptation costs use a bottom-up methodology, in which the investment needed for adaptation is projected for separate sectors. For long-term adaptation cost projections, Integrated Assessment Models (IAMs) are better suited. IAMs are tools created to assess the effects of the economy on climate change and vice versa. As these models use a top-down approach they provide less sectoral detail, but have the advantage that residual damages and adaptation costs are directly connected. This section first summarises the findings for short-term adaptation costs estimates from literature, after which we use an IAM to project long-term adaptation costs for different scenarios.

4.1 The near to mid-term to 2050

Of all existing studies on near to mid-term adaptation costs, the World Bank study (World Bank 2010b) is the only study that projects sectoral adaptation costs on the regional level over a period of time. For this reason we focus here on the World Bank study. It should be noted that the World Bank study projects similar total adaptation costs to most of the other studies.

The World Bank study projects adaptation costs up to 2050 under two climate change scenarios: A relatively dry scenario from the CCSM3 climate model of the Commonwealth Scientific and Industrial Research Organization (CSIRO) and a relatively wet scenario from Mk3.0 climate model of the National Centre for Atmospheric Research (NCAR). Both climate scenarios are based on the A2 SRES emissions scenario. In both climate models, average global temperature change reaches about 2°C by 2050 above pre-industrial levels, albeit on track for around 4°C warming globally by 2100. To determine adaptation costs, it is assumed that countries would adapt to the level at which they would enjoy the same level of welfare as they would without climate change. While this overestimates adaptation costs, other factors lead to an underestimation of adaptation costs. For instance, neither soft (institutions and policies) adaptation options, nor private adaptation (see Section 4.2) are considered in the study.

Table 4.1 provides an overview of the adaptation measures on which adaptation costs were based by the World Bank study. It should be noted that some overlap in adaptation costs between sectors is possible in the World Bank study. For instance, overlaps in adaptation costs between infrastructure and water resources management are not taken into account, as the cost of adaptation was estimated for each sector separately and in parallel. However, for some adaptation measures, like rural roads, an attempt was made to eliminate overlapping expenditures. For ecosystems, no assessment of adaptation costs could be made because of gaps in scientific understanding of the impact of climate change on ecosystems.

Sector	Adaptation measures
Extreme weather events	Empowering women through improved education to reduce household vulnerability to weather-related disasters
Human health	For diarrheal diseases: breastfeeding promotion; vaccination against rotavirus, cholera, and measles; and improvements in water supply and sanitation. For malaria: use of insecticide-treated bednets; artemisinin-based combination therapy; indoor residual spraying; and intermittent presumptive treatment in pregnancy.

Sector	Adaptation measures
Agriculture	Agricultural research Roads Irrigation efficiency and expansion
Water supply	Increasing the capacity of surface reservoir storage or recycling, rainwater harvesting, and desalination
Riverine flood protection	Dikes and polders
Coastal zone protection	Beach nourishment Dike building Port upgrades
Infrastructure	Health and education (if not captured elsewhere) Power generation, electricity transmission and distribution Roads (mainly paved roads) Other transport Urban infrastructure (drainage, public buildings, and other assets) Water and sewage treatment

Table 4.1 – Adaptation measures considered in the World Bank (2010a) study

Total average annual adaptation costs are projected at USD 14-15 billion in Sub-Saharan Africa and about USD 2.5 billion in the Middle East and North Africa region. Figure 4.1 shows how these numbers relate to other world regions. In absolute numbers, adaptation costs in Sub-Saharan Africa are projected to be (slightly) lower than in the East Asia & Pacific and Latin America & Caribbean regions, but higher than in Europe & Central Asia. However, adaptation costs as a share of GDP are projected to be much higher in Sub-Saharan Africa (about 0.5% on average between 2010-2050) than in any other world region (other regions range from 0.08% to about 0.2%), indicating the relative importance of adaptation funding in Sub-Saharan Africa.



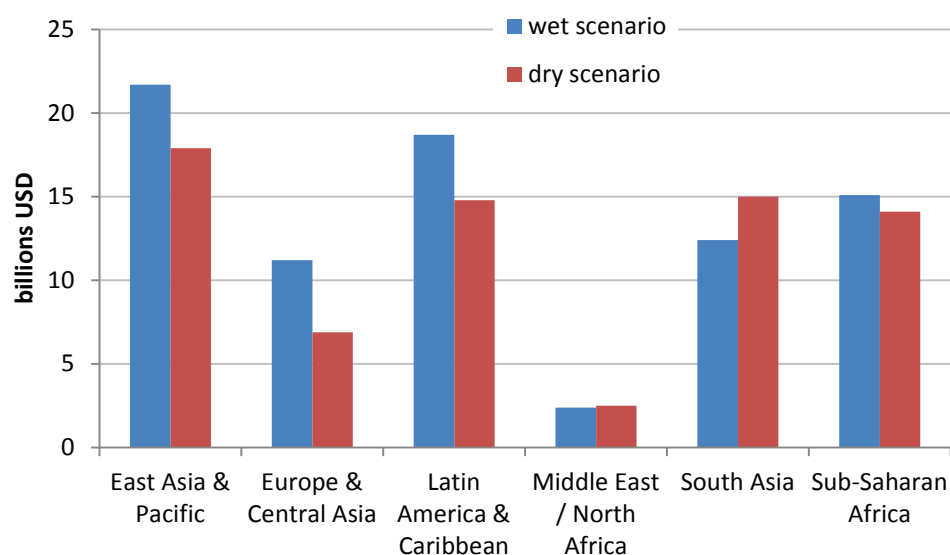


Figure 4.1 Average annual costs between 2010 and 2050 of adapting to 2°C warming globally by 2050, by world region. Source: World Bank (2010b)

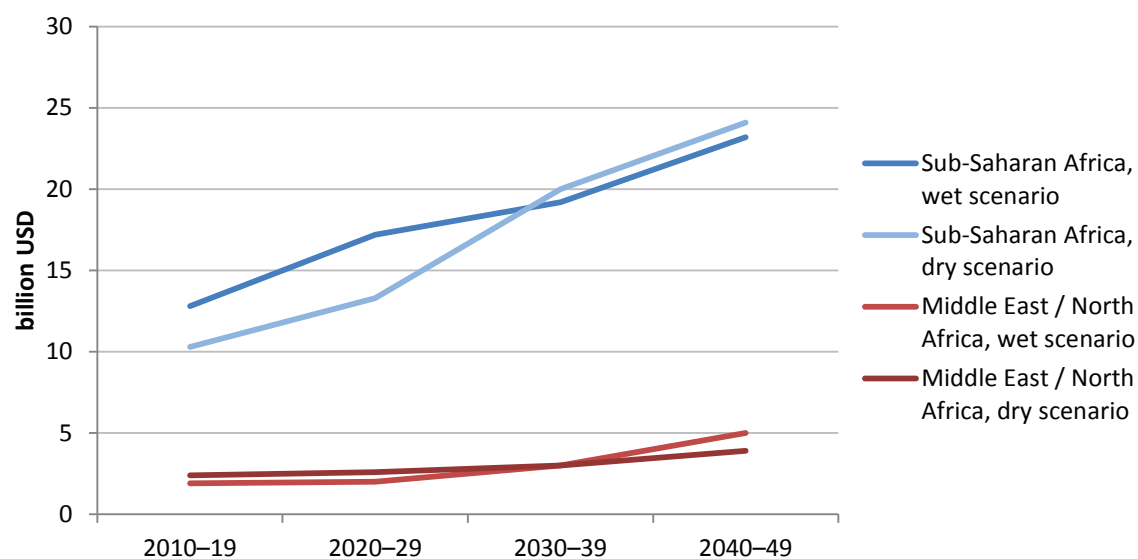


Figure 4.2 Average annual costs between 2010 and 2050 of adapting to 2°C warming globally by 2050, by world region. Source: World Bank (2010a)

Figure 4.2 shows that adaptation costs are projected to increase over time, from USD 10-13 billion annually between 2010 and 2019, to USD 23-24 billion annually between 2040 and 2049 in Sub-Saharan Africa. While this indicates a doubling of adaptation costs over time, adaptation costs as a share of GDP are expected to decrease as GDP is projected to grow faster than adaptation costs.

In Sub-Saharan Africa, the highest adaptation costs are projected to be needed in the water supply, coastal zone protection, infrastructure, and agriculture sectors (Figure 4.3). For Middle East & North Africa, the greatest need for adaptation is in infrastructure, coastal zone protection, and adapting to extreme weather events. As both climate change scenarios generally project less rainfall in North Africa, adaptation costs for riverine flood protection are negative – implying that less flood protection is needed with climate change than in the reference scenario without climate change.

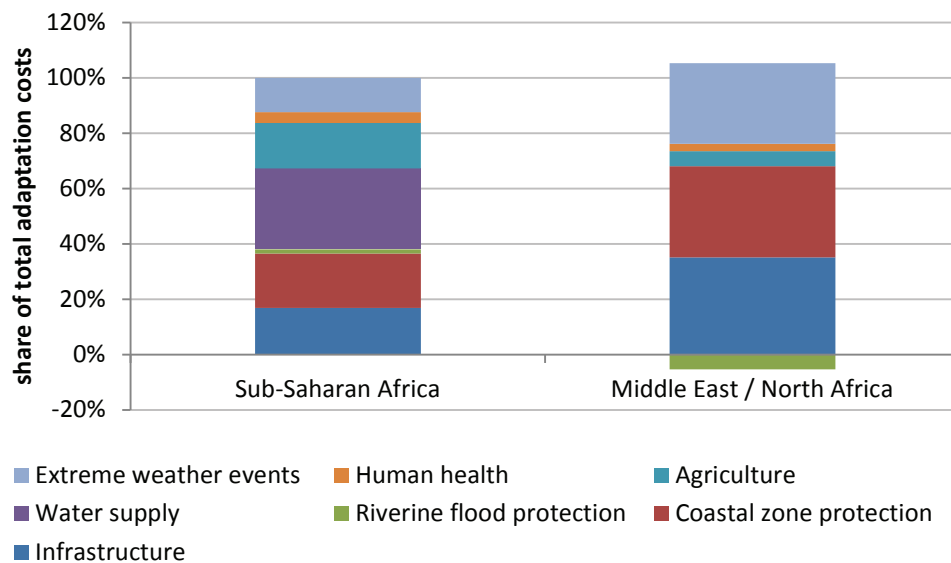


Figure 4.3 Share of total average annual costs between 2010 and 2050 of adapting to 2°C warming globally by sector. Source: own calculations based on World Bank (2010a)

4.2 The long term

Several attempts have been made to assess the damages associated with climate change for various world regions. These damage assessments have been completed within the context of IAMs. Though the estimates of climate change damages vary among IAMs, they are remarkably similar given the large uncertainties in assessing future climate change damages and the different impacts considered in the different models. In this report we apply the AD-RICE model (de Bruin 2011), which has the advantage that it explicitly considers the role of adaptation in combatting climate change damages. The AD-RICE model is based on the RICE model developed by Nordhaus (see Nordhaus 2011 for a description of the latest model).

The AD-RICE model includes three forms of adaptation, namely autonomous adaptation, anticipatory adaptation and a separate anticipatory category for sea-level rise adaptation. This distinction has been made to enable a more accurate description of the costs and benefits of different forms of adaptation and hence the total adaptation costs. Autonomous adaptation describes adaptation measures that can be taken in reaction to climate change or climate change stimuli. This form of adaptation comes at a relatively low cost and is generally undertaken by individual households and therefore is referred to as *private* adaptation. Examples of this form of adaptation are the use of air conditioning and changing crop planting times. When autonomous adaptation decisions are made, the decision-maker weighs the direct benefits of adaptation (reduced damages) against the direct costs of adaptation. The costs and benefits fall within the same time period (in this model a decade). The benefits of autonomous adaptation are only felt for one time period, i.e. autonomous adaptation only provides protection from climate change damages for a decade.

Anticipatory adaptation, on the other hand, refers to adaptation measures that require investments long before the effects of climate change are felt. Anticipatory adaptation is modeled as investments made in order to build adaptation capital. The benefits of this capital are not felt immediately but create a stream of benefits in the future. Anticipatory adaptation investments made today will create adaptation capital in the next decade. The adaptation capital reduces damages as long as it still is in place. The adaptation capital depreciates over time, i.e. it does not last forever and will need to be replenished. This form of adaptation usually requires large-scale investments made by governments and therefore is a form of *public* adaptation. Examples of this form of adaptation are research and development into new crop types or the construction of a dam for irrigation purposes. When the decision-maker decides how much to invest in the building of adaptation capital, he needs to weigh the costs made now against a stream of future benefits. The investment costs are made now whereas the actual benefits in the form of reduced damage are expected in the future. As adaptation capital reduces damages for several decades, the decision-maker will need to sum and discount the future benefits and weigh these against the investment cost.

The final form of adaptation, sea-level rise adaptation, falls under the category of anticipatory adaptation, but is distinguished due to its uniquely high effectiveness. The construction of seawalls is considered to be a highly effective way of avoiding a large amount of potential damages. The damages of sea-level rise and the associated adaptation costs depend on the level

of sea-level rise and not the temperature.

Besides creating more accurate estimates, the distinction between anticipatory and autonomous adaptation is also very useful in understanding future adaptation challenges. Autonomous adaptation is expected to be undertaken by individual decision-makers (e.g. individuals, households, firms) in reaction to the climate and climate impacts they face. There can be restrictions limiting this, e.g. lack of knowledge or knowhow, especially in developing regions such as Africa, however these restrictions are far less problematic than in the case of anticipatory adaptation. Anticipatory adaptation requires large amounts of investments decades before actual climate impacts are felt. Furthermore, anticipatory adaptation often benefits large numbers of individuals, who would need to cooperate to implement and fund the adaptation measures. This requires government leadership, which in Africa can be a significant challenge.

Though IAMs such as AD-RICE are built to assess climate change effects in the long term, we present short-term estimates of adaptation costs as well compare these with the World Bank estimates described in Section 4.1. Such a comparison is not without difficulties, as the underlying methodology is very different. As mentioned in the beginning of this section, the World Bank applies a bottom-up approach, while AD-RICE use a top-down approach. Another important methodological difference lies in the level of adaptation. In the AD-RICE model the optimal level of adaptation and the associated *optimal* adaptation costs are estimated. At this level, the marginal costs of adaptation equals the marginal costs of residual damages so that total economic costs of climate change are minimised. The World Bank assumes the level of adaptation needed to retain the same welfare level as would be attained without climate change (see Section 4.1). The latter approach leads to a higher level of adaptation, and hence to higher adaptation costs. On the other hand, the World Bank excluded autonomous adaptation in their study, which could lead to lower cost estimates compared to AD-RICE.

Figure 4.4 presents the total adaptation costs for all impact sectors in USD billions. Comparing Figure 4.4 to Figure 4.2, AD-RICE and the World Bank project similar average annual adaptation cost estimates during 2010-2050. The main difference is that adaptation costs increase more steeply over time according to the AD-RICE estimates. Figure 4.4 also shows the importance of scenarios for the level of adaptation costs, especially after 2030. In the RCP8.5 scenario, adaptation costs in Africa are projected at USD 70 billion by 2045, whereas in the RCP3 scenario, they are only half this amount. This indicates that the level of emission control can have an enormous effect on adaptation costs in Africa.

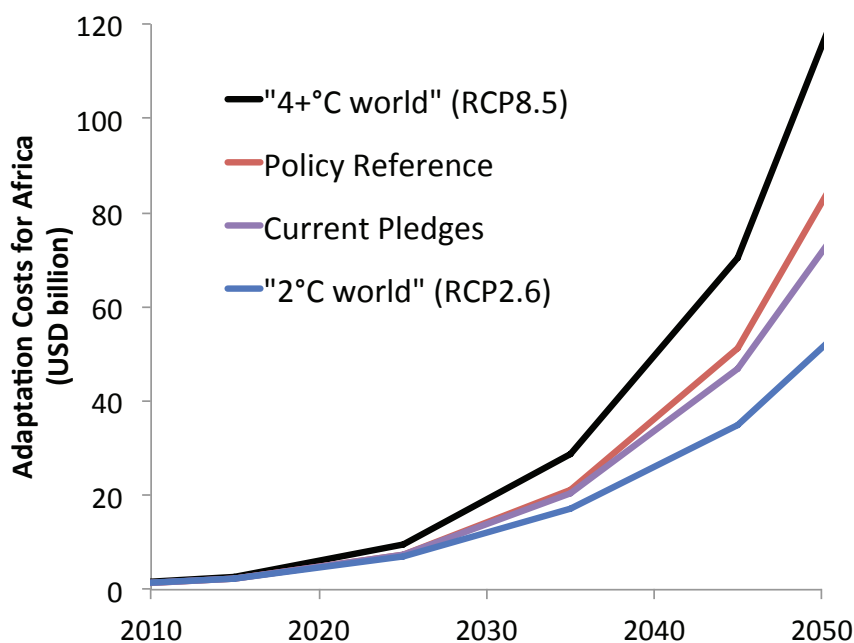


Figure 4.4 Total adaptation costs for Africa for all sectors in billion 2005 USD over time. Source: own calculations using the AD-RICE model.

To understand the magnitude of adaptation costs in the long term, we present adaptation costs as a percentage of GDP. Figure 4.5 shows the estimated total adaptation costs over time for four of the emission scenarios presented in Figure 1.1 (Chapter 1). Again we see a clear and rapid increase of adaptation costs over time, unlike the World Bank study, which estimates that adaptation costs as a percentage of GDP will decrease.

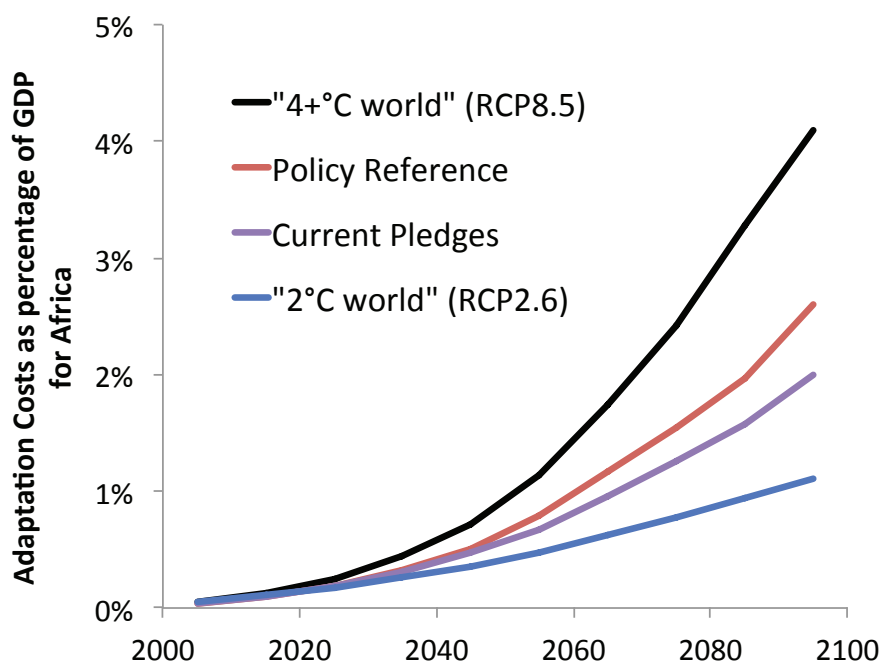


Figure 4.5 Total adaptation costs for all sectors as a percentage of Africa's GDP over time.

Source: own calculations using the AD-RICE model.

Figure 4.6A and 4.6B present total adaptation costs as a percentage of GDP plotted against the level of temperature change. Figure 4.6A shows the relationship between temperature and non sea-level rise adaptation costs and 4.6B shows the relationship between temperature and sea-level rise adaptation costs. The figures show that the different scenarios lead to different levels of adaptation costs for the same level of temperature increase.

In the case of non sea-level rise adaptation costs, the faster the rate of temperature increase, i.e. the steeper the increase of climate change impacts, the larger the resulting adaptation costs. This is due to the stream of benefits of anticipatory adaptation. As much of Africa lacks infrastructure to adapt autonomously to climate change, most of its adaptation costs consists of investments in adaptation capital. In developed regions this is not necessarily the case: for example, energy infrastructure in developed regions allows more widespread use of air conditioning, water is more readily available for use in irrigation, and alternative crop seeds can be purchased on the market. In developing regions, such infrastructure needs first to be built in order to enable autonomous adaptation. When investing in anticipatory adaptation the investment costs now are weighed against a stream of benefits over the next decades. If the temperature is rising rapidly this will result in increasingly large adaptation benefits over time, resulting in higher investments and hence higher costs. Another reason why the adaptation costs are higher with more rapid temperature increases is because the temperature change will occur earlier. Because the stream of anticipatory adaptation benefits is discounted over both time and income (more emphasis is put on relieving poor generations) adaptation benefits felt earlier in time carry more weight than benefits felt later in time when Africa is assumed to have a much higher income per capita.

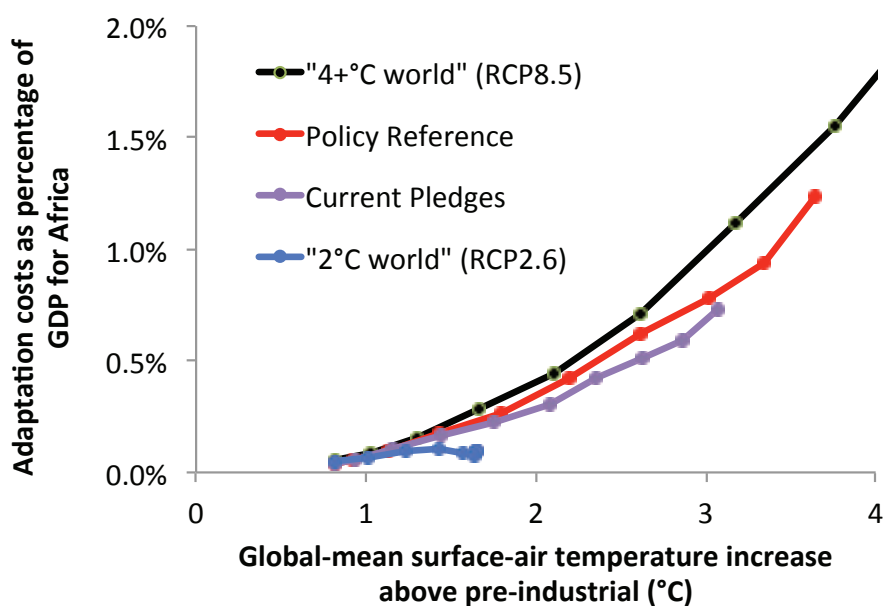


Figure 4.6A Total adaptation costs for all sectors excluding the sea-level rise sector as a percentage of GDP for different levels of temperature change (increase compared to 1900). Source: own calculations using the AD-RICE model.

In the case of sea-level rise adaptation costs, we see the opposite relationship, i.e. the earlier the temperature change reaches a pre-defined level, the lower the adaptation costs. This is because of the large inertia of the climate-system components driving sea-level rise (i.e. oceans, ice sheets and ice caps). Due to this inertia, sea-level rises at a slower pace relative to temperature changes. Though in scenario RCP8.5, for example, the temperature level is high, the sea-level rise is still at a low level compared to the temperature level, because not enough time has passed to allow the impacts on oceans and ice sheets to “catch up” and have a large effect on sea-level rise.

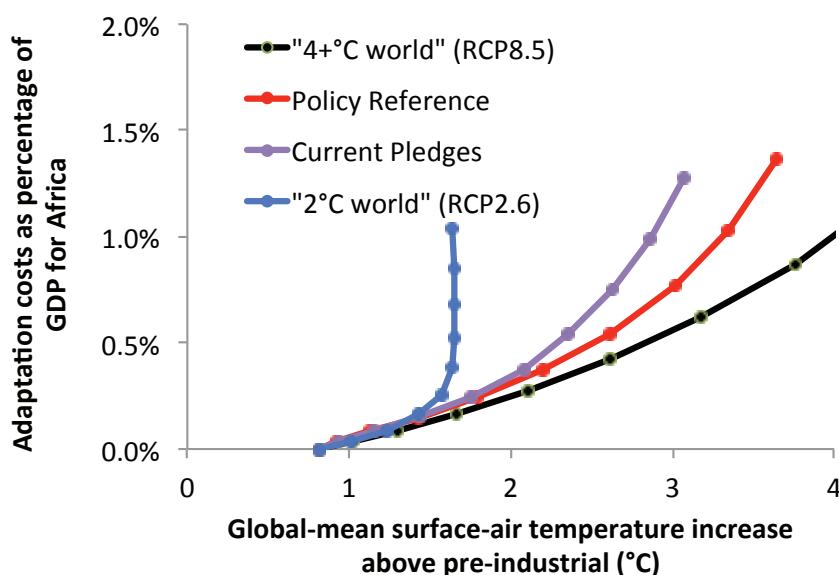


Figure 4.6 Total adaptation costs for sea-level rise sector as a percentage of GDP for different levels of temperature change (increase compared to 1900). Source: own calculations using the AD-RICE model.

Figure 4.7 shows the shares of the different adaptation costs as a proportion of the total adaptation costs for the year 2050 and 2100 for the different scenarios. As described above, Africa shows a high share of anticipatory adaptation costs as a proportion of total adaptation costs. Sea-level rise adaptation costs are relatively constant over scenarios, which, as mentioned above, is due to the large inertia in the oceans and ice sheets, and hence small differences in sea-level rise

between the scenarios.

Whether the fraction of anticipatory adaptation costs increases or decreases over time depends on the scenario. There are two mechanisms at work here. Firstly, as mentioned earlier, steep temperature increases will increase the level of anticipatory adaptation. Secondly, as damages grow, anticipatory adaptation will increase after which autonomous adaptation will increase. In other words, as damages grow, anticipatory adaptation becomes more effective, increasing the level of anticipatory adaptation. However, after a certain level of adaptation capital, further investments create relatively small benefits and autonomous adaptation becomes relatively more beneficial.

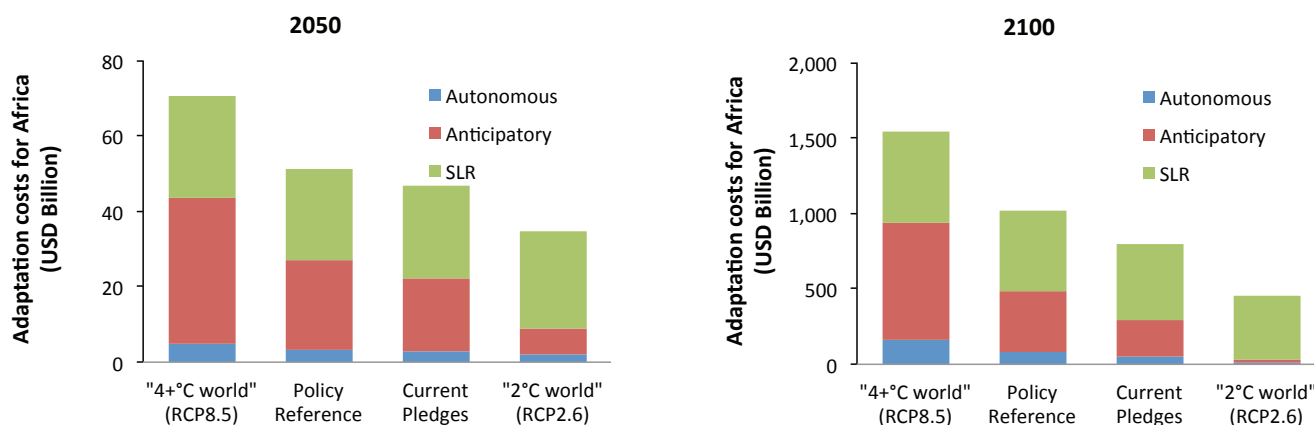


Figure 4.7 Total adaptation costs decomposed in autonomous adaptation costs, anticipatory adaptation costs and sea-level rise adaptation costs (left panel for the year 2050, right panel for the year 2100). Source: own calculations using the AD-RICE model.

To get a better understanding of the benefits of adaptation in Africa, Figure 4.8A and B compare the net climate change damages (the sum of adaptation costs and residual damages) for all sectors except sea-level rise with and without adaptation for the year 2050 (Figure 4.8A) and 2100 (Figure 4.8B). Sea-level rise damages are omitted here as adaptation costs and damages are very similar across scenarios. We focus on non sea-level rise sectors to emphasise the differences across scenarios. Net sea-level rise damages are expected to be five times higher in the case of non sea-level rise adaptation. We look at 4 adaptation scenarios, namely adaptation, no adaptation, no autonomous adaptation and no anticipatory adaptation. As can be seen from Figure 4.8, the additional net damages due to limited adaptation are extremely high. Especially in the long run, damages can more than double when adaptation is not undertaken. This highlights the enormous need for adaptation in Africa. We also see that once again the large role of anticipatory adaptation in Africa is confirmed. Damages increase significantly more without anticipatory adaptation than without autonomous adaptation. The role of autonomous adaptation is, however, more important in the short run (until 2050).

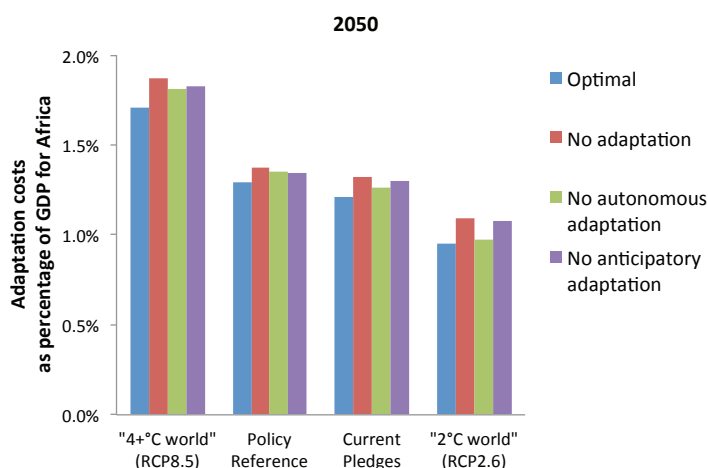


Figure 4.8A Net climate change damages (adaptation costs and residual damages) as a percentage of GDP for different adaptation scenarios for all non sea-level rise sectors for the year 2050. Source: own calculations using the AD-RICE model.

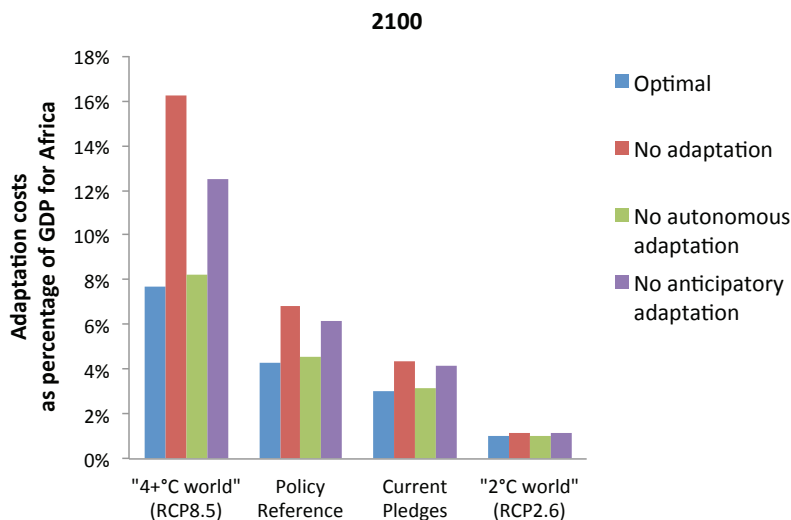


Figure 4.8B Net climate change damages (adaptation costs and residual damages) as a percentage of GDP for different adaptation scenarios for all non sea-level rise sectors for the year 2100. Source: own calculations using the AD-RICE model.

4.3 Discussion

As mentioned before, assessing future climate change adaptation costs is a complex undertaking that involves a large amount of uncertainty. Though the estimates in this section can give us a better understanding of the adaptation needs facing Africa in the future, they have their limitations. In this subsection we will discuss the limitations and caveats of the estimates presented in sections 4.1 and 4.2.

With regard to the estimates of the near to medium term adaptation costs of the World Bank study, important limitations are the stylised characterisation of government decision-making, the limited range of climate and economic growth assumptions, the limited scope in economic breadth, and the simplified characterisation of human behaviour.

The characterisation of government decision-making is probably the most problematic element of the World Bank study. A general assumption in the study is that decision makers know with certainty what the future climate will be. In reality, current climate knowledge does not permit even probabilistic statements about country-level climate outcomes. For most durable investment decisions, decision-makers know with certainty only that climate in the future will differ from climate today. This implies that country-level decision makers face the problem of maximising the flexibility of investment programs to take advantage of new climate knowledge as it becomes available. The assumption of perfect foresight about the future climate means that the costs of adaptation are biased downward.

The study further did not explore the full uncertainty range of adaptation costs, as only two future climate projections were studied and one economic growth path. While adaptation costs are relatively insensitive to economic growth projections (more growth increases the assets at risk, but raises incomes and reduces vulnerability), different climate projections can have large impacts on the costs of adaptation.

With regard to economic breadth, the World Bank study estimated only the additional public sector (budgetary) costs imposed by climate change, not overall economic damages. While for estimating the adaptation gap budgetary costs are the most relevant, these must not be confused with overall economic damages, which can be both larger and smaller.

Finally, in several aspects the study assumed a simplified characterisation of human behaviour. First, “hard” options involving engineering solutions were favoured over “soft” options, such as early warning systems, community preparedness programs, watershed management, urban and rural zoning, and water pricing. The most important reason was that it is easier to cost hard measure and because it is impossible to know, in a global study, whether the institutional preconditions for soft adaptation measures are present. Second, migration is not taken into account by the World Bank study. As population movements across countries may impose heavy infrastructure costs in areas receiving substantial numbers of migrants, this limitation may lead to an underestimation of adaptation costs (however, this is more likely to become a serious issue in the second half of the century). Third, an upward bias is caused by the fact that no effort was made to identify whether the resources invested in one sector to counter the effects of climate change would have yielded a higher benefit-cost ratio in another sector. Finally, another upward bias can be caused by the assumption that innovation and technical change have no effect on future adaptation costs.

Regarding the long-term estimates the most prominent limitations are uncertainties about the impacts of climate change, incomplete inclusion of the role of institutions and the characterisation of the decision-maker. The estimates of adaptation costs from the AD-RICE model are based on the impact assessment of the RICE model, which as discussed in the beginning of section 4.2 involves uncertainty. It is impossible to predict climate change damages with certainty and opinions differ on the expected level of climate change damages. As a sensitivity analysis, different damage estimates are applied in Appendix 2 to understand how damage assumptions affect the estimated adaptation costs in the AD-RICE model.

The AD-RICE model is an applied economic model, which tries to capture the complexities of future climate change and its impacts. Naturally it is not possible to capture all details, characteristics and mechanisms involved in the adaptation process. Specifically non-financial aspects of adaptation are hard to define in an economic framework.

An issue that is expected to play a large role in Africa concerning adaptation that is not fully captured in this model is institutions. It has long been recognised that a region's institutions will be instrumental in enabling effective adaptation (Kelly and Adger 2000, Agrawal 2008). Agrawal (2008) argues that institutions affect adaptation in the following three ways: they structure impacts and vulnerability, they mediate between individual and collective responses to climate impacts and thereby shape outcomes of adaptation, and they act as the means of delivery of external resources to facilitate adaptation, and thus govern access to such resources. Thus institutions have an instrumental role in e.g. disseminating information on future climate change and adaptation options, providing funding possibilities, coordinating collective actions, developing infrastructure etc. In many African countries institutions do not fulfil these functions satisfactorily (see e.g. Crane 2013).

Specifically information/knowledge and funding are expected to play a key role in enabling adaptation in Africa. Bryan et al. (2009) survey farmers in Ethiopia and find that almost half of the respondents named lack of knowledge/information and lack of funding as a restriction for them to adapt. In economic models of adaptation, it is often assumed that information and capital will flow freely and markets will provide adaptation options where needed, hence that institutions will effectively enable adaptation. To try to deal with this issue, in the AD-RICE model the role of institutions and infrastructure is included as a need for investments in adaptation capital. A part of the adaptation capital built is defined as institutions and infrastructure. However, obviously this is a crude representation of actual adaptation procedures and is likely to underestimate the actual adaptation costs involved.

As described in the case of the WB study, in the AD-RICE model too the decision-maker is assumed to have perfect foresight of future climate change and its impacts. This is an unrealistic assumption.



05 The Adaptation Gap(s)

The estimates of adaptation costs in Africa presented in Chapter 4 show that the costs for adaptation are projected to increase for all emission scenarios. In the high-emission scenarios (ranging from “current pledges” to the high business-as-usual scenario RCP8.5), costs are estimated at about USD 45-70 billion per year by the 2040s, while the estimate for a 2°C pathway RCP2.6 amounts to \$35 billion per year by the 2040s. The difference in these estimates clearly highlights the key role played by global mitigation efforts in reducing the costs for adaptation in Africa. If the costs under any emissions scenario are higher than funding available, Africa is confronted with an Adaptation Funding Gap, which is projected to exacerbate the existing “adaptation deficit”, i.e. the existing capacity to cope with current climate variability (Burton, 2004).

However, the Adaptation Funding Gap should not hide the existence of other adaptation gaps. Bridging the Adaptation Funding Gap by keeping global mean temperature below 2°C degrees above pre-industrial levels, and increasing funding for adaptation in Africa and globally, may not be sufficient to efficiently implement adaptation measures on the ground. Other major capacity gaps were identified in the literature and through experience on the ground. These lead to low “absorptive capacity” and are related to attracting funding and implementing adaptation activities in Africa and in the developing world in general. Accessing international funding remains challenging at every stage of the funding process for countries with technical, institutional and human capacity constraints. The first challenge lies in developing national adaptation and resilience-building plans and strategies in line with countries’ development priorities, including necessary stakeholders consultation processes at national and sub-national level. The compulsory exercise in the National Adaptation Plan guidelines to identify climate change vulnerabilities may be arduous for countries lacking scientific capacity. Scientific capacity to assess risks, vulnerabilities and associated uncertainties needs to be strengthened in order to kick-start the need-focused adaptation processes. Second, capacity constrained countries have difficulties to formulate costed, bankable, result-oriented projects and programmes derived from strategies and plans. Third, those countries also face difficulties in meeting internationally agreed fiduciary, financial management standards, and internationally agreed environmental and social safeguards and therefore might not get their national entities accredited and granted direct access. Fourth, capacity-constrained countries face difficulties in attracting private sector investment and more generally in attracting and mixing various available sources and partners.

The remainder of this chapter provides an overview of current climate finance pledges and funds available globally and for Africa to adapt to climate change, and compares these to the cost estimates of the previous chapter.

5.1 Global pledged and available funding for adaptation

Article 4.4 of the United Nations Framework Convention on Climate Change (Rio de Janeiro, 1992) enshrines the commitment by developed countries to support developing countries’ adaptation to climate change impacts: “The developed country Parties and other developed country Parties included in Annex II shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects”. In this regard, the Global Environment Facility (GEF) (1998) and more recently the Green Climate Fund (GCF) (2012) have been designated as the Operating Entities of the Financial Mechanism of the Convention and financial instruments have been established to finance costs of adaptation in developing countries. Over the recent years, a growing amount of funding has been made available to fund adaptation projects through bilateral and multilateral channels and more funding is currently available and pledged in international funds.

5.1.1 Funding disbursed for adaptation, globally and in Africa

Using the OECD DAC database, we estimated the funding disbursed globally and in Africa for climate change adaptation through bilateral and multilateral channels for the years 2010 and 2011. The figures displayed in the table (Table 5.1.1) below do not however fully account for the funding channelled through multilateral and regional development banks (including the World Bank).

Geographical scale and type of funding	Policy objective ¹⁸	2010 (USD million)	2011 (USD million)
Global climate finance (in million)	Principal	\$16,468.22	\$9,089.80
	Significant	\$9,611.87	\$11,628.47
Global adaptation funding (in million)	Principal	\$3,080.48	\$1,849.43
	Significant	\$5,375.29	\$6,489.95
Africa climate finance (in million)	Principal	\$3,707.86	\$1,226.33
	Significant	\$2,951.60	\$3,075.35
Africa adaptation funding (in million)	Principal	\$742.87	\$453.57
	Significant	\$1,509.02	\$1,790.23

Table 5.1.1 – Disbursed climate funds in 2010 and 2011 (based on OECD/DAC data)

For projects represented in the OECD/DAC database, funding for global adaptation efforts represented approximately 20 per cent of the total climate finance disbursed in 2010 and in 2011 and adaptation in Africa received about 25 per cent of the adaptation funding. The OECD/DAC database presents significant caveats that affect the accuracy and interpretation of the figures shown in Table 5.2.1, and especially the actual share of adaptation funding. First, the OECD/DAC database accounts for both private and public flows of funding, and includes Official Development Assistance (ODA), Other Official Flows (OOF), private flows and net private grants. Due to this broader reporting scope, the total amount of funding reported in the OECD/DAC database is larger than the amount pledged under Fast Start Finance. For the period 2010-2011, the total funding approved or committed for adaptation according to the OECD/DAC database was about USD 28 billion, compared to USD 28 billion for the (longer) 2010-2012 period for FSF (Polycarp et al., 2012). In total a volume of USD 38.99 billion has been reported by developed countries, as of 2 June 2013, as pledged, allocated and implemented Fast Start Finance. This includes USD 35.9 billion in public finance and USD 3 billion in private finance (Japan) (Fallasch and De Marez, 2013).

Second, the dichotomy between principal and significant funding does not allow for a clear attribution of funding to adaptation activities, in the sense that only an – unspecified – share of the funding for the projects with a significant policy objective may contribute to adaptation.

Third, and on the other hand, not all funding dedicated to adaptation projects from public or private sources is included in the reporting system. For example, not all multilateral sources are included and a few smaller OECD non-DAC-member donor countries are not included.

Finally, support to autonomous, or reactive, adaptation may or may not be included in the OECD/DAC database.

The relative level of funding for adaptation globally compared to mitigation funding found for the OECD/DAC database is very close to figures estimated by other organisations. For example, according to the Climate Funds Update database (<http://www.climatefundsupdate.org/>), about 18 percent of the project funding disbursed was dedicated to climate change adaptation projects. Analysis of Fast Start Finance over the 2010-2012 period indicates that adaptation accounted for 21-29% of the funding (Fallasch and De Marez, 2013).

¹⁸ OECD distinguishes between principal and significant. The objective is principal when policy objectives can be identified as being fundamental in the design of the activity and which are an explicit objective of the activity. The objective is secondary when policy objectives are not one of the principal reasons for undertaking the activity.

5.1.2 Available multilateral funding for climate change adaptation in Africa and globally

Under and outside the UNFCCC, there are a number of funds financing climate change adaptation projects and activities in developing countries. Two GEF administrated Convention trust funds finance among others, adaptation projects in developing country Parties: the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF). These funds are resourced through voluntary contributions by developed country Parties. Under the Kyoto Protocol, the Adaptation Fund, which is sourced through the monetisation of a share of proceeds of CDM projects¹⁹ and voluntary contributions by developed country Parties, finances, including through direct access, concrete adaptation projects in developing countries, in particular those that are the most vulnerable. Outside the UNFCCC, the World Bank has initiated the Pilot Program for Climate Resilience (PPCR), which is part of the Climate Investment Funds (CIFs) that have a sunset clause upon the operationalisation of the GCF.

The amount of funding available varies according to the different funds, as well as their modalities for access, for replenishment and their focus. The following table (table 5.2.2) displays the main characteristics of these funds and the amount of funding they have allocated to adaptation since their inception.

The developed country Parties to the UNFCCC have committed to provide new and additional funds rising to USD 100 billion annually by 2020, from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources, to support adaptation and mitigation actions in developing countries. "A significant share of new multilateral funding for adaptation should flow through the Green Climate Fund" (Decision 1/CP.16, para 100). Modalities and principles for the allocation of funding for adaptation are to be further developed in the UNFCCC and in the GCF Board.

Fund	Supervising entity / Location	Amount (disbursed or available)	Funding sources
LDCF ¹⁹	UNFCCC (administered by the GEF)	USD 604.8 million (disbursed since 2003)	Voluntary contributions by developed country Parties
SCCF ²⁰	UNFCCC (administered by the GEF)	USD 258 million (disbursed since 2003)	Voluntary contributions by developed country Parties
Adaptation Fund ²¹	Kyoto Protocol	USD 325.05 million (credited as of March 2013)	Share of proceeds of the CDM (2% of CERs) and voluntary contributions by developed country Parties
PPCR ²²	World Bank	USD 1.3 billion (pledged) USD 306 million (approved)	Donor countries
GCF	UNFCCC	To be determined	Public, private and alternative sources

Table 5.1.2 – Existing multilateral funds addressing adaptation (sources: see footnotes)

19 During the first commitment period (2008- 2012). The Conference of the Parties held in Doha in 2012 decided to extend the share of proceeds to all the flexible mechanisms for the second commitment period (2013-2020); modalities are still being discussed.

20 Source : Progress report on LDCF and SCCF, June 2013, The GEF, page 1
http://www.thegef.org/gef/sites/thegef.org/files/documents/GEF-LDCF.SCCF_14-03.%20Progress%20Report%20on%20the%20Least%20Developed%20Countries%20Fund%20and%20Special%20Climate%20Change%20Fund,%202013-05-23_1.pdf

21 Update on Status of Resources and CER monetization, presentation by the trustee to the adaptation committee, July 2013, https://www.adaptation-fund.org/sites/default/files/AFB.B.21.Inf_4%20Trustee%20Presentation%20on%20CER.pdf

22 <https://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/cifinfographicPPCR.png>; Report on the financial status of the SCF, April 2013, The world Bank Group, page 4
https://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/SCF_TFC.10_Inf2_Trustee_Report_on_the_Financial_Status_of_the_SCF.pdf

5.2 The funding gap

The adaptation costs estimates for Africa shown in Section 4, between USD 35 billion and USD 70 billion annually by the 2040s for the low and high emission scenarios. The section below provides a comparison of these estimated adaptation costs in Africa with indications of existing and projected funding.

5.2.1 - The Emissions Gap fuelling the Adaptation Gap

Parties at the UNFCCC have agreed to keep average the global temperature increase below 2°C above pre-industrial level. Meeting this temperature objective requires strong mitigation actions from all Parties, with developed country Parties taking the lead, however current mitigation pledges are inadequate to meet the objective set by the international community. The United Nations Environment Program (UNEP) used the term “Emissions Gap” to point to the difference between the political 2°C objective and the Parties’ emissions reduction pledges. The global ambition level for mitigation is also projected to have significant consequences for adaptation costs in Africa. By the 2040s, estimated adaptation costs in the policy reference and current pledges scenarios (leading to 3.5-4°C globally by 2100) are projected to be 1.5 times higher than the costs for adaptation in a 2°C pathway, and twice the latter by the 2070s.

Figure 5.2.1 illustrates the difference in adaptation costs between different temperature pathways. The adaptation costs for the highest business-as-usual, policy reference and current pledges scenarios are compared to the low emission scenario, which leads to approximately 2°C of warming by the end of the 21st century.

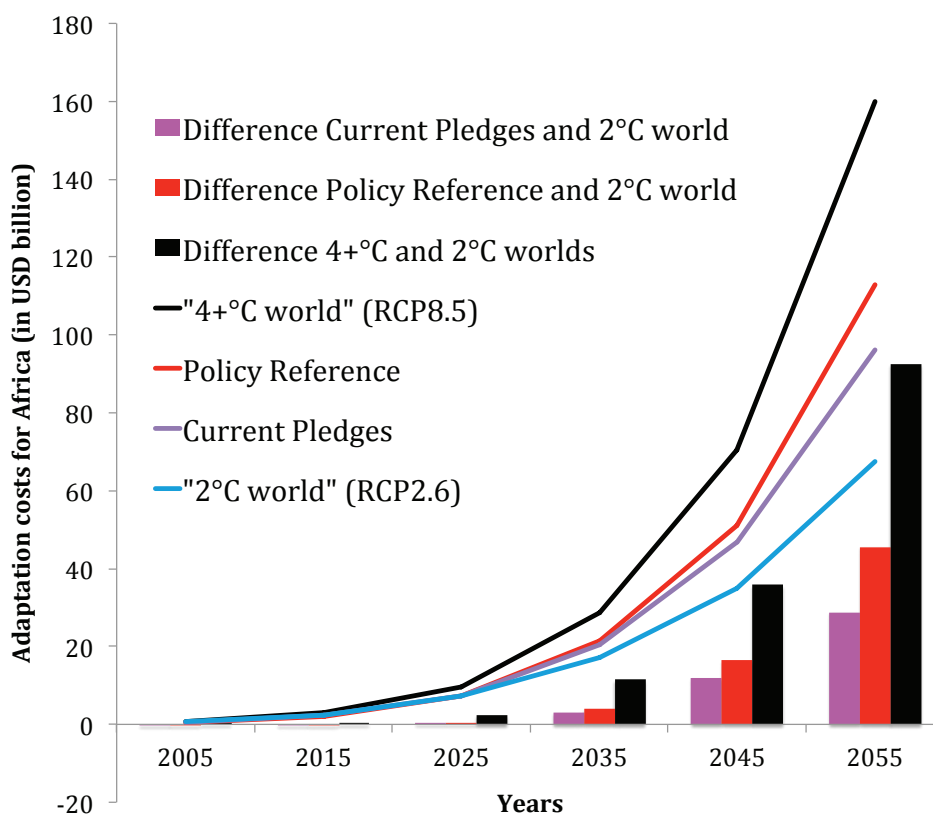


Figure 5.2.1 – Autonomous and anticipatory adaptation cost estimates for the high emission, policy reference and current pledges scenarios compared to adaptation costs in the low emission 2°C scenario. Source: own calculations using the AD-RICE model.

The difference between adaptation costs in Africa between the policy reference scenario and the 2°C scenario (RCP2.6) increases very steeply, from about USD 4 billion per year around the 2030s to approximately USD 45 billion per year by the 2050s and USD 75 billion per year by the 2070s. Therefore, strong mitigation actions undertaken by Parties at the UNFCCC that contribute to keeping global mean temperature increase below 2°C are projected to have large positive effects in terms of minimising the costs for adaptation in Africa.

5.2.2 The Adaptation Funding Gap

At the 15th Conference of the Parties in 2009 and at the subsequent Conferences of the Parties (COP), developed country Parties have committed to providing USD 100 billion from public and private sources in the context of meaningful mitigation actions and transparency on implementation for climate action in developing countries. Based on the experience of Fast Start Finance (USD 30 billion funding pledged by developed countries for the period 2010-2012), analyses have shown that between 21 and 29% per cent of the total funding was allocated to adaptation actions in developing countries (some 'mixed funding' cannot be clearly attributed to either mitigation or adaptation) (Fallasch and De Marez 2013). For the Fast Start Finance period, the COP16 decision stated that allocation of the pledged USD 30 billion should be balanced between adaptation in mitigation activities.

Assuming strong mitigation efforts from the UNFCCC Parties to bridge the Emission Gap and keep global mean temperature increase below 2°C by the end of the century, we calculated the rate at which adaptation funding for Africa needs to increase to meet adaptation costs from 2010 to 2055. The rate of increase of adaptation funding to meet adaptation costs in Africa is particularly relevant considering the current negotiations on long-term finance at the UNFCCC. The following table (Table 5.2.2) displays adequate rates of increase of adaptation funding to meet adaptation costs in Africa through to 2025 and subsequently through to 2055, based on the limited information from traceable amounts of funding received in 2011 (source OECD/DAC). In light of the limitations of the DAC database discussed in Section 5.1.1, we use two different starting points to calculate the required scaling up from 2011 to 2020, i.e. "principal" purpose adaptation funding, likely underestimating the level in 2011 and hence overestimating the rate of scaling up; and "significant" purpose, for which the opposite applies.

	2011	2020s	2050s	2050s
			RCP2.6	Policy Reference
Adaptation funding in Africa (only principal in USD billion)	0.5			
Adaptation funding in Africa (significant and principal in USD billion)	2.2			
Adaptation costs (in USD billion)		7	67	110
Adaptation funding increase per year between 2011 and 2020s (only principal %)		22%		
Adaptation funding increase per year between 2011 and 2020s (significant and principal, in %)		9%		
Between 2020s-2050s (in %)			7%	10%

Table 5.2.2 – Rates of increase of adaptation funding between 2011 and 2055 to meet adaptation costs for Africa in the low emissions 2°C scenario (RCP2.6) and policy reference scenarios. Source: own calculations based on OECD/DAC database and AD-RICE model.

Our estimates demonstrate that in a 2°C temperature increase scenario, meeting adaptation costs in Africa by the 2020s will require a steep increase in annual funding for adaptation in Africa from 2011 levels onwards by about 10-20% annually. Present trends in funding will not meet these needs and there is at present no clear and agreed pathway or identified sources of funding through which such a rapid scaling up can be achieved.

With reference to the USD 100 billion funding by 2020 commitment, there is no agreed understanding of how these funds should be allocated between developing countries and regions, nor between mitigation and adaption. Hence, it is not possible to judge whether this commitment would deliver the USD 7-15 billion per year estimated in this report by 2020 as adaptation costs for Africa. What is clear is that there is at present no agreed program to meet this commitment.

A sustained increase in funding will be needed well beyond the 2020s. In order to fully meet adaptation costs in Africa beyond the 2020s, adaptation funding should increase further by about 7% per year from the 2020s to the 2050s, assuming funding levels by 2020 already meet the costs.

Ensuring the same optimal level of adaptation in the higher emissions scenarios will require a yet steeper increase post-2020. For example, to keep pace with the increase in adaptation costs in the Policy Reference scenario, annual adaptation funding should increase by 10% every year from the 2020s to the 2050s and beyond. Unmet adaptation needs are projected to aggravate the residual damages of African countries (as Figure 4.8 in Section 4 illustrates).

Ensuring the measurement, reporting and verification of financial support delivered to developing country Parties is a key element. The limitations and caveats of funding data that apply to the OECD/DAC database, for example, illustrate that access to accurate and reliable data on support for adaptation and mitigation in developing countries is particularly complex. There is currently no comprehensive international database reporting climate finance flows from donor countries or agencies through multilateral and bilateral channels. Transparency is a prerequisite to know with any certainty whether existing and pledged funding is adequate to bridge the adaptation gaps in Africa and other low-income regions. Common reporting format tables adopted in Doha are still to be improved, especially in terms of how to account for private investment leveraged through public funding towards developed country Parties' commitments. Likewise, in order to ensure that the funding for climate change adaptation is efficiently used, monitoring and evaluation systems for the implementation of adaptation projects in developing countries should be strengthened through capacity building and technical assistance.

Meeting adaptation costs in Africa is a twofold challenge. First, it requires strong mitigation actions to keep global mean temperature increase below 2°C. Beyond this temperature, adaptation costs in Africa might become unmanageable. Furthermore, even if global mean temperature increase is kept below 2°C, existing global climate funding will still not be sufficient to meet Africa's and the rest of the world's adaptation costs. Adaptation funding will therefore have to be scaled up at a rate consistent with the costs for adaptation on the continent.



References

- Cheung, W. W. L., Dunne, J., Sarmiento, J. L., & Pauly, D. (2011). Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. *ICES Journal of Marine Science*, 68(6).
- Cheung, William W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., & Pauly, D. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16(1), 24–35. doi:10.1111/j.1365-2486.2009.01995.x
- Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., ... Whetton, P. (2007). Regional Climate Projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, ... H. L. Miller (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, U.K., and New York, U.S.: Cambridge University Press.
- Cinner, J. E., McClanahan, T. R., Graham, N. A. J., Daw, T. M., Maina, J., Stead, S. M., ... Bodin, O. (2012). Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, 22.
- Crane, T.A., (2013). "The role of local institutions in adaptive processes to climate variability. The cases of southern Ethiopia and southern Mali. Boston : Oxfam America, 2013 (Oxfam research report) - 34 p.
- Dai, A. (2012). Increasing drought under global warming in observations and models. *Nature Climate Change*, Published online 05 August.
- Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2011). Exposure of developing countries to sea-level rise and storm surges. *Climatic Change*, 106(4), 567–579. doi:10.1007/s10584-010-9959-6
- de Bruin, K. C., R. B. Dellink and R. S. J. Tol (2009). "AD-DICE: An implementation of adaptation in the DICE model." *Climatic Change* 95(1-2): 63-81.
- de Bruin, K.C., (2011)."Distinguishing between proactive (stock) and reactive (flow) adaptation ". CERE Working paper 2011:8.
- Deutsche Bank Research. (2008). *Climate change and tourism: where will the journey lead?*
- Doherty, R. M., Sitch, S., Smith, B., Lewis, S., & Thornton, P. K. (2010). Implications of future climate and atmospheric CO₂ content for regional biogeochemistry, biogeography and ecosystem services across East Africa. *Global Change Biology*, 16, 617–640.
- Döll, P. & Zhang, J. (2010). Impact of climate change on freshwater ecosystems: a global-scale analysis of ecologically relevant river flow alterations. *Hydrology and Earth System Sciences Discussions*, 7(1), 1305–1342. doi:10.5194/hessd-7-1305-2010
- Döll, Petra. (2009). Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment. *Environmental Research Letters*, 4(3), 35006. doi:10.1088/1748-9326/4/3/035006
- Douglas, I., Alam, K., Maghenda, M., McDonnell, Y., Mclean, L., & Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. *Environment and Urbanization*, 20(1), 187–205. doi:10.1177/0956247808089156
- Drinkwater, K., Beaugrand, G., Kaeriyama, M., Kim, S., Ottersen, G., Perry, R. I., ... Takasuka, A. (2010). On the processes linking climate to ecosystem changes. *Journal of Marine Systems*, 79, 374–388.

- Adams, M. A. (2013). Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future. *Forest Ecology & Management*, 294, 250–261.
- Adger, W.N., (2006). "Vulnerability". *Global Environmental Change*, Volume 16, Issue 3, Pages 268-281.
- Ahmed, S. A., Diffenbaugh, N. S., & Hertel, T. W. (2009). Climate volatility deepens poverty vulnerability in developing countries. *Environmental Research Letters*, 4(3).
- Agrawal, A. (2008). "The role of local institutions in adaptation to climate change." Washington DC: World Bank.
- Allison, E. H., Perry, A. L., Badjeck, M. C., Adger, W. N., Brown, K., Conway, D., ... Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10, 173–196.
- Anthoff, D. and R.S.J. Tol (2013). "The Uncertainty about the Social Cost of Carbon: A Decomposition Analysis Using FUND". *Climatic Change* 117(3): 515-530.
- Batisha, A. F. (2012). Adaptation of Sea Level Rise in Nile Delta Due to Climate Change. *Earth Science and Climate Change*, 3(2).
- Beaumont, L. J., Pitman, A., Perkins, S., Zimmermann, N. E., Yoccoz, N. G., & Thuiller, W. (2011). Impacts of climate change on the world's most exceptional ecoregions. *Proceedings of the National Academy of Sciences of the United States of America*, 108(6), 2306–11. doi:10.1073/pnas.1007217108
- Bergengren, J. C., Waliser, D. E., & Yung, Y. L. (2011). Ecological sensitivity: a biospheric view of climate change. *Climatic Change*, 107, 433–457.
- Betts, R. A., Golding, N., Gonzalez, P., Gornall, J., Kahana, R., Kay, G., ... Wiltshire, A. (2013). Climate and land use impacts on global terrestrial ecosystems, fire, and river flows in the HadGEM2-ES Earth System Model using Representative Concentration Pathways. *Biogeosciences Discussions*, 10, 6171–6223.
- Beyene, T., Lettenmaier, D. P., & Kabat, P. (2010). Hydrologic impacts of climate change on the Nile River Basin: implications of the 2007 IPCC scenarios. *Climatic Change*, 100, 433–461.
- Bond, W. J., & Parr, C. L. (2010). Beyond the forest edge: Ecology, diversity and conservation of the grassy biomes. *Biological Conservation*, 143(10), 2395–2404. doi:10.1016/j.biocon.2009.12.012
- Brander, K. M. (2007). Global fish production and climate change. *Proceedings of the National Academy of Sciences*, 104(50), 19709–19714.
- Burke, M. B., Lobell, D. B., & Guarino, L. (2009). Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Global Environmental Change*, 19, 317–325.
- Butt, T. A., McCarl, B. A., Angerer, J., Dyke, P. T., & Stuth, J. W. (2005). The Economic and Food Security Implications of Climate Change in Mali. *Climatic Change*, 68, 355–378.
- Caminade, C., Ndione, J. A., Kebe, C. M. F., Jones, A. E., Dnuor, S., Tay, S., ... Morse, A. P. (2011). Mapping Rift Valley fever and malaria risk over West Africa using climatic indicators. *Atmospheric Science Letters*, 12, 96–103.
- Carter, M. R., Little, P. D., Mogues, T., & Negatu, W. (2007). Poverty Traps and Natural Disasters in Ethiopia and Honduras. *World Development*, 35(5), 835–856. doi:10.1016/j.worlddev.2006.09.010
- Fallasch, F. & De Marez, L. (2013) Cashing-up At the end of Fast Start Finance: What can we learn for long-term finance? Policy Brief, Climate Analytics, Germany
- FAO. (2012). *The State of Food Insecurity in the World 2012* (pp. 1–65). Rome.
- Förster, H., & Lilliestam, J. (2009). Modeling thermoelectric power generation in view of climate change. *Regional Environmental Change*, 10(4), 327–338. doi:10.1007/s10113-009-0104-x
- Fung, F., Lopez, A., & New, M. (2011). Water availability in +2°C and +4°C worlds. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, 369(1934), 99–116. doi:10.1098/rsta.2010.0293
- Giannini, A., Biasutti, M., Held, I. M., & Sobel, A. H. (2008). A global perspective on African climate. *Climatic Change*, 90(4), 359–383.
- Gonzalez, P., Tucker, C. J., & Sy, H. (2012). Tree density and species decline in the African Sahel attributable to climate. *Journal of Arid Environments*, 78, 55–64. doi:10.1016/j.jaridenv.2011.11.001

- Gonzalez, Patrick, Neilson, R. P., Lenihan, J. M., & Drapek, R. J. (2010). Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography*, 19(6), 755–768. doi:10.1111/j.1466-8238.2010.00558.x
- Goulden, M., Conway, D., & Persechini, A. (2009). Adaptation to climate change in international river basins in Africa: a review. *Hydrological Sciences Journal*, 54(5).
- Hagemann, S., Chen, C., Clark, D. B., Folwell, S., Gosling, S. N., & Haddeland, I. (2013). Climate change impact on available water resources obtained using multiple global climate and hydrology models, 1321–1345. doi:10.5194/esdd-3-1321-2012
- Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. *Nature Climate Change*.
- Hare, W., W. Cramer, M. Schaeffer, A. Battaglini and C. Jaeger (2011). "Climate hotspots: key vulnerable regions, climate change and limits to warming." *Regional Environmental Change* 11(0): 1-13.
- Hein, L., Metzger, M. J., & Leemans, R. (2009). The local impacts of climate change in the Ferlo, Western Sahel. *Climatic Change*, 93, 465–483.
- Hinkel, J., Brown, S., Exner, L., Nicholls, R. J., Vafeidis, A. T., & Kebede, A. S. (2011). Sea-level rise impacts on Africa and the effects of mitigation and adaptation: an application of DIVA. *Regional Environmental Change*, 12(1), 207–224. doi:10.1007/s10113-011-0249-2
- Hof, A. F., M. G. J. den Elzen and D. P. van Vuuren (2010). "Including adaptation costs and climate change damages in evaluating post-2012 burden-sharing regimes." *Mitigation and Adaptation Strategies for Global Change* 15(1): 19-40.
- Hope, C.W. (2011). "The Social Cost of CO2 from the PAGE09 Model". *Economics Discussion Papers*, No 2011-39, Kiel Institute for the World Economy.
- Hunt, A., & Watkiss, P. (2010). Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change*, 104(1), 13–49. doi:10.1007/s10584-010-9975-6
- Kelly, P.M., Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47, 325–352
- Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters*, 7(3), 034032. doi:10.1088/1748-9326/7/3/034032
- Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Doll, P., Kabat, P., Jimenez, B., ... Shiklomanov, I. A. (2007). Freshwater resources and their management. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hansen (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.
- Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Temesgen Deressa, Mbaye Diop, Helmy Mohamed Eid, K. Yefi Fosu, Glwadys Gbetibouo, Suman Jain, A. M., Mano, R., ... Dinar, A. (2006). Will African Agriculture Survive Climate Change? *The World Bank Economic Review*, 20(3), 367–388. doi:10.1093/wber/lhl004
- Kurukulasuriya, Pradeep, & Rosenthal, S. (2003). *Climate Change and Agriculture: A Review of Impacts and Adaptations*. Washington, D.C.
- Lam, V. W. Y., Cheung, W. W. L., Swartz, W., & Sumaila, U. R. (2012). Climate change impacts on fisheries in West Africa: implications for economic, food and nutritional security. *African Journal of Marine Science*, 34(1), 103–117. Retrieved from <http://www.tandfonline.com/doi/abs/10.2989/1814232X.2012.673294>
- Liu, J., Fritz, S., van Wesenbeeck, C. F. A., Fuchs, M., You, L., Obersteiner, M., & Yang, H. (2008). A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change. *Global and Planetary Change*, 64, 222–235.
- Lloyd, S. J., Kovats, R. S., & Chalabi, Z. (2011). Climate Change, Crop Yields, and Undernutrition: Development of a Model to Quantify the Impact of Climate Scenarios on Child Undernutrition. *Environmental Health Perspectives*, 119(12).
- Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science (New York, N.Y.)*, 319(5863), 607–10. Retrieved from <http://www.sciencemag.org.ezp.lib.unimelb.edu.au/content/319/5863/607.full>
- Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*

(New York, N.Y.), 333(6042), 616–20. doi:10.1126/science.1204531

MacDonald, A. M., Calow, R. C., MacDonald, D. M. J., Darling, W. G., & Dochartaigh, B. É. Ó. (2009). What impact will climate change have on rural groundwater supplies in Africa? *Hydrological Sciences Journal*, 54(4), 690–703. Retrieved from <http://www.tandfonline.com/doi/abs/10.1623/hysj.54.4.690>

McClean, C. J., Lovett, J. C., Kuper, W., Hannah, L., Sommer, J. H., Barthlott, W., ... Taplin, J. R. D. (2005). African Plant Diversity and Climate Change. *Annals of the Missouri Botanical Garden*, 92(2).

McMichael, A. J., & Lindgren, E. (2011). Climate change: present and future risks to health, and necessary responses. *Journal of Internal Medicine*, (270), 401–413. doi:10.1111/j.1365-2796.2011.02415.x

McMichael, C., Barnett, J., & McMichael, A. J. (2012). An Ill Wind? Climate Change, Migration, and Health. *Environmental Health Perspectives*, 120(5).

Meissner, K. J., Lippmann, T., & Sen Gupta, A. (2012). Large-scale stress factors affecting coral reefs: open ocean sea surface temperature and surface seawater aragonite saturation over the next 400 years. *Coral Reefs*, 31(2), 309–319. Retrieved from <http://www.springerlink.com/index/10.1007/s00338-011-0866-8>

Merino, G., Barange, M., Blanchard, J. L., Harle, J., Holmes, R., Allen, I., ... Rodwell, L. D. (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? *Global Environmental Change*, 22(4), 795–806. doi:10.1016/j.gloenvcha.2012.03.003

Michel, D., & Pandya, A. (2010). *Coastal zones and climate change*. Washington.

Milano, M., & et al. (2013). Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. *Hydrological Sciences Journal*, 58(3), 498–518.

Ndebele-Murisa, M. R., Musil, C. F., & Raitt, L. (2010). A review of phytoplankton dynamics in tropical African lakes. *South African Journal of Science*, 106(1/2), 13–18. doi:10.4102/sajs.v106i1/2.64

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., ... Zhu, T. (2010). *Food Security, Farming, and Climate Change to 2050 - Scenarios, results, policy options*. Washington D.C.

Neumann, J. E., Emanuel, K. A., Ravela, S., Ludwig, L. C., & Verly, C. (2013). Assessing the risk of cyclone-induced storm surge and sea level rise in Mozambique.

Nordhaus, W. (2011). “Estimates of the social cost of carbon: background and results from the RICE-2011 model”. Cowles Foundation Discussion Paper No. 1826

Oxfam (2007). *Adapting to climate change – What’s needed in poor countries, and who should pay*. Washington, Oxfam.

Pandey, D. N., Gupta, A. K., & Anderson, D. M. (2003). Rainwater harvesting as an adaptation to climate change. *Current Science*, 85(1), 46–59.

Parr, C. L., Gray, E. F., & Bond, W. J. (2012). Cascading biodiversity and functional consequences of a global change-induced biome switch. *Diversity and Distributions*, 18(5), 493–503. doi:10.1111/j.1472-4642.2012.00882.x

Pascual, M., Ahumada, J. A., Chaves, L. F., Rodo, X., & Bouma, M. (2006). Malaria resurgence in the East African highlands: Temperature trends revisited. *Proceedings of the National Academy of Science*, 103(15), 5829–5834.

Patz, J. A., Olson, S. H., Uejo, C. K., & Gibbs, H. K. (2008). Disease emergence from global climate and land use change. *Med Clin N Am*, 92, 1473–1491.

Phillips, M. R., & Jones, A. L. (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. *Tourism Management*, 27(3), 517–524. doi:10.1016/j.tourman.2005.10.019

Riahi, K., S. Rao, V. Krey, C. Cho, V. Chirkov, G. Fischer, G. Kindermann, N. Nakicenovic and P. Rafaj (2011). “RCP 8.5—A scenario of comparatively high greenhouse gas emissions.” *Climatic Change* 109(1): 33–57.

Rogelj, J., C. Chen, J. Nabel, K. Macey, W. Hare, M. Schaeffer, K. Markmann, N. Höhne, K. Krogh Anderson and M. Meinshausen (2010). “Analysis of the Copenhagen Accord pledges and its global climatic impacts, a snapshot of dissonant ambitions.” *Environmental Research Letters* 5(3): 034013.

Roudier, P., Sultan, B., Quirion, P., & Berg, A. (2011). The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, 21, 1073–1083.

Schaeffer, M., L. Gohar, J. Lowe, E. Kriegler, K. Riahi and D. P. van Vuuren (2013). “Mid- and long-term climate projections

for fragmented and delayed-action scenarios." *Technological Forecasting & Social Change* Submitted.

Schaeffer, M., W. Hare, S. Rahmstorf and M. Vermeer (2012). "Long-term sea-level rise implied by 1.5°C and 2°C warming levels." *Nature Climate Change* 2(12): 867-870.

Scheiter, S., & Higgins, S. I. (2009). Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Global Change Biology*, 15(9), 2224–2246. doi:10.1111/j.1365-2486.2008.01838.x

Schellnhuber, H. J., Hare, W., Serdeczny, O., Adams, S., Coumou, D., Frieler, K., ... Warszawski, L. (2012). Turn down the heat: Why a 4°C warmer world must be avoided.

Schellnhuber, H. J., Hare, W., Serdeczny, O., Schaeffer, M., Adams, S., Baarsch, F., ... Rocha, M. (2013). Turn down the heat: Climate extremes, regional impacts and the case for resilience.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N. W., Clark, D. B., & Dankers, R. (2013). Multi-model assessment of water scarcity under global warming. *Proceedings of the National Academy of Sciences of the United States of America*, 110(1), 1–13. doi:10.1073/pnas.0709640104

Schilling, J., Freier, K. P., Hertig, E., & Scheffran, J. (2012). Climate change, vulnerability and adaptation in North Africa with focus on Morocco. *Agriculture, Ecosystems and Environment*, 156, 12–26.

Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 106(37), 15594–8. Retrieved from <http://www.pnas.org/content/106/37/15594>

Scott, D., Gössling, S., & Hall, C. M. (2012). International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 3(3), 213–232. doi:10.1002/wcc.165

Simpson, M. C., Gössling, S., Scott, D., Hall, C. M., & Gladin, E. (2008). Climate change adaptation and mitigation in the tourism sector: frameworks, tools and practices. Paris.

Smit, W., & Parnell, S. (2012). Urban sustainability and human health: an African perspective. *Current Opinion in Environmental Sustainability*, 4, 443–450.

Smith, P., & Olesen, J. E. (2010). Synergies between the mitigation of, and adaptation to, climate change in agriculture. *The Journal of Agricultural Science*, 148(05), 543–552. doi:10.1017/S0021859610000341

Stern, N. (2006). *The Economics of Climate Change*, The Stern Review. Cambridge, UK, Cambridge University press.

Steyn, J. N., & Spencer, J. P. (2012). Climate change and tourism: Implications for South Africa. *African Journal for Physical Health Education Recreation and Dance*, 18(1), 1–19.

Thieme, M. L., Lehner, B., Abell, R., & Matthews, J. (2010). Exposure of Africa's freshwater biodiversity to a changing climate. *Conservation Letters*, 3, 324–331.

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101, 113–127.

Thornton, Philip K, Jones, P. G., Ericksen, P. J., & Challinor, A. J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, 369(1934), 117–36. doi:10.1098/rsta.2010.0246

Trenberth, K. E. (2010). Changes in precipitation with climate change. *Climate Research*, 47, 123–138.

Turner, L. W., Vu, C. J., & Witt, S. F. (2012). Comparative Tourism Shocks. In C. H. S. Hsu & W. C. Gartner (Eds.), *The Routledge Handbook of Tourism Research* (pp. 110–119). Routledge.

UN Habitat. (2011). *Cities and Climate Change: Global Report on Human Settlements 2011*.

UNEP Global Environmental Alert Service. (2013). Africa without ice and snow. *Environmental Development*, 5, 1460155.

UNEP (2010). *The Emissions Gap Report*. Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2° C or 1.5° C? A preliminary assessment, United Nations Environment Programme (UNEP): 53.

UNEP (2011). *Bridging the Emissions Gap*. A UNEP Synthesis Report, United Nations Environment Programme (UNEP): 53.

UNEP (2012). *The Emissions Gap Report 2012*. A UNEP Synthesis Report, United Nations Environment Programme

(UNEP): 62.

United Nations Department of Economic and Social Affairs. (2012). World Urbanization Prospects, The 2011 Revision (pp. 1–50). New York, USA.

UNWTO. (2008). Climate Change and Tourism – Responding to Global Challenges. Madrid / Paris.

Van Vliet, M. T. H., Franssen, W. H. P., Yearsley, J. R., Ludwig, F., Haddeland, I., Lettenmaier, D. P., & Kabat, P. (2013). Global river discharge and water temperature under climate change. *Global Environmental Change*. doi:10.1016/j.gloenvcha.2012.11.002

van Vuuren, D., E. Stehfest, M. den Elzen, T. Kram, J. van Vliet, S. Deetman, M. Isaac, K. Klein Goldewijk, A. Hof, A. Mendoza Beltran, R. Oostenrijk and B. van Ruijven (2011). “RCP2.6: exploring the possibility to keep global mean temperature increase below 2°C.” *Climatic Change* 109(1): 95-116.

Vine, E. (2011). Adaptation of California’s electricity sector to climate change. *Climatic Change*, 111(1), 75–99. doi:10.1007/s10584-011-0242-2

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, a, Green, P., ... Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, 467(7315), 555–61. doi:10.1038/nature09440

Wilby, R. L., & et al. (2010). Evidence needed to manage freshwater ecosystems in a changing climate: Turning adaptation principles into practice. *Science of the Total Environment*, 408, 4150–4164.

Williams, J. W., Jackson, S. T., & Kutzbach, J. E. (2007). Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Sciences*, 104(14).

Willmott, E., Le Courtois, A., Baker Gallegos, J., & Datta, N. (2011). Guide to Climate Change Adaptation in Cities (pp. 1–106). Washington, D.C.

World Bank. (2013). Electricity production from hydroelectric sources (% of total).

World Bank (2010a). The Costs to Developing Countries of Adapting to Climate Change - New Methods and Estimates. The Global Report of the Economics of Adaptation to Climate Change Study: Consultation Draft. Washington, D.C., The World Bank Group.

World Bank (2010b). The economics of adaptation to climate change - a synthesis report. Washington, D.C., The World Bank Group.

World Health Organization. (2013). Climate Change and Health - A tool to estimate health and adaptation costs (pp. 1–55). Copenhagen, Denmark.

World Travel and Tourism Council. (2013). Travel & Tourism - Economic Impact 2013 Africa (pp. 1–24). London, UK.

UNDP (2007). Human Development Report 2007/2008. New York, UNDP.

UNFCCC (2007). Investment and Financial Flows to Address Climate Change. Bonn.

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., Marker, M., Schulze, K., Van Vuuren, D. P., ... Agency, E. A. (2005). Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology*, 11(10), 1557–1564. doi:10.1111/j.1365-2486.2005.01008.x

appendix 1. overview of adaptation options and measures

Human/ Economic activities or sectors	Climate change stressors	Impacts	Options or measures proposed by research	EACC country case studies (World Bank)	Projects being implemented (description, cost, people benefiting)
Water resources	- Drought and floods (extreme/catastrophic events) - Modified quantity and seasonality of run-off - Increased/decreased river flow - Reduced rates of groundwater recharge	- Decreased access to safe drinking water	- Increased but sustainable use of groundwater (Kundzewicz et al., 2007; MacDonald, Calow, MacDonald, Darling, & Dochtaigh, 2009) - Increased storage in reservoirs (Kundzewicz et al., 2007) - Inter-basin transfer via pipes and canals (Ragab & Prudhomme, 2002) - Desalination of seawater (Kundzewicz et al., 2007; Ragab & Prudhomme, 2002) - Increased water-use efficiency and water recycling (Kundzewicz et al., 2007) - Use of water markets to reallocate water between uses or economic incentives such as metering and pricing (Kundzewicz et al., 2007)	- Promotion of water storage during wet season for usage in dry season (EACC Ghana) - Improved land use practices such as avoidance of uncontrolled deforestation, protection of river courses, and de-sedimentation of reservoirs (EACC Ghana) - Increased water transfer from the Volta basin (EACC Ghana)	- Reducing the vulnerability of communities in drought-prone areas of southern Darfur State through improved water harvesting practices (NAPA Sudan) - Promotion of Rain Water Harvesting and Development of an Integrated Management System for Fresh Water Bodies (NAPA Sierra Leone)
Agriculture (including livestock)	- Drought and floods (extreme/catastrophic events) - Modified rainfall patterns (and seasonality) - Heat extremes	- Crop losses - Decreased crop yield - Decreased range-land vegetation yield (affecting biodiversity and livestock feed supply)	- Synergistic adaptation-mitigation measures: (1) measures that reduce soil erosion, (2) measures that reduce leaching of nitrogen and phosphorus, (3) measures for conserving soil moisture, (4) increasing the diversity of crop rotations by choices of species or varieties, (5) modification of microclimate to reduce temperature extremes and provide shelter, (6) land use change involving abandonment or extensification of existing agricultural land, or avoidance of the cultivation of new land (Smith & Olesen, 2010) - cost effective greenhouse gas (GHG) Better control of grazing pressure; selection of more drought tolerant taxa; water harvesting techniques (Belgacem & Louhaichi, 2013)	- Irrigation and drainage infrastructure improvements in water storage capacity (EACC Ghana) - R&D in agriculture (EACC Ethiopia, Ghana and Mozambique)	- Promoting crop insurance (NAPA Ethiopia) - Modernization and diversification of agricultural production for food security improvement (NAPA Cape Verde) - Capture of surface water for agriculture and provision of food for livestock (NAPA Chad)

Human/ Economic activities or sectors	Climate change stressors	Impacts	Options or measures proposed by research	EACC country case studies (World Bank)	Projects being implemented (description, cost, people benefiting)
Fisher- ies	Marine	- Decreased access to fish proteins and associated economic benefits	- Relieve pressure on species by temporarily closing fisheries or by diversifying to new gears and target species (Cinner et al., 2012)		Increasing fish production through aquaculture and conservation of post harvest fishery products (NAPA Gambia)
		- Decreased access to fish proteins and associated economic benefits	- Install coastal defences, provide compensatory habitat (Wilby & et al, 2010)		
	Fresh- water	- Decreased access to fish proteins and associated economic benefits	- Plant trees to provide shading - Create thermal refugia such as deep pools (Wilby & et al, 2010)		
		- Decreased access to fish proteins and associated economic benefits	- Reduce water abstraction - Introduce compensation schemes and water recycling - Monitor and diffuse sources of nutrient, micro-organic compounds, viral and bacterial pathogens (Wilby & et al, 2010)		
Tourism	- Cyclones and floods (extreme/catastrophic events) - Sea-level rise - Loss of biodiversity	- Reduced economic and social benefits (incomes, jobs)	- Scientific monitoring survey programmes to assess changes and necessary protection of biodiversity, eg in Cape Floral region, South Africa (UNWTO, 2008: 108) - Protected area redesign or definition, ie. Zoning certain areas, protecting larger areas, creation of migratory corridors for threatened species (UNWTO, 2008: 108) - Reduction or removal of external stresses such as overused, pollution and in the case of marine resources, agricultural run-off (UNWTO, 2008: 108)		Strengthening and stabilizing ecotourism based rural livelihoods (NAPA Lesotho) World Bank in collaboration with Mozambique Ministry of Tourism to finance a sea wall and possibly ecological protection options (eg vegetated sand dunes) to prevent damage and shoreline erosion due to cyclones and storm surges in Vilankulo town, Inhambana Province, Mozambique (Simpson et al 2008)
Health	- Extreme/catastrophic events) - Heat extremes	- Diminution of overall population's health and potentially life expectancy	- Widening the geographic range of infectious disease surveillance programmes (McMichael & Lindgren, 2011) - Disasters early-warning systems (floods, droughts, fires....) (World Health Organization, 2013) - Regulation to control water- and vector borne diseases (World Health Organization, 2013)		Support and assistance to the rural communities of the regions of Savanes and Plateaux to prevent and fight vector borne diseases (NAPA Togo) Prevention against water-borne diseases and other seasonal pathologies in rural areas (NAPA Central Africa Republic)

Human/ Economic activities or sectors	Climate change stressors	Impacts	Options or measures proposed by research	EACC country case studies (World Bank)	Projects being implemented (description, cost, people benefiting)
Cities	- Cyclones and floods (extreme/catastrophic events) - Sea-level rise - Heat extremes	- Diminution of overall population's health and potentially life expectancy - Increased economic damages	- Seawall and other infrastructures protecting against coastal flooding (Willmott, Le Courtois, Baker Gallegos, & Datta, 2011) - Development of city-level food storage capacity (Willmott et al., 2011) - Air-conditioning (Hunt & Watkiss, 2010)	- Sea dikes, - Creating and enhancing construction of river dikes to protect ports and harbors, - Beach nourishment; - Increased maintenance - Coastal mangrove protection and management (EACC Ghana)	Coastal Defense System for the Cities of Buchanan and Monrovia: Reducing the vulnerability of coastal urban areas (Monrovia, Buchanan) to erosion, floods, siltation and degraded landscapes (NAPA Liberia) Climate proofing sanitation in urban areas (NAPA Zambia)
Energy	- Modified rainfall patterns (and seasonality) - Heat extremes - Increased/decreased river run-off	- Decreased access to reliable electricity sources	- Investment in renewable energy and energy efficiency (Willmott et al., 2011) - Adoption of more energy efficient building codes (Vine, 2011)	- More dams (EACC Ethiopia) - More dams, wind and solar in the mix, and more fossil fuel fired power plants (EACC Mozambique)	Adaptation of households to climate change through awareness-raising and capacity building on the use of renewable energy (solar energy) and energy-efficient stoves in the areas vulnerable to climate change and with highly degraded soils (Benin) Promote Wind, Solar and Biogas Energy Use as a Supplement to Hydropower Energy (Lesotho)

APPENDIX 2: uncertainty and sensitivity analysis for top-down adaptation costs

As discussed in Section 4, there are many uncertainties involved in the estimation of adaptation costs. To address the long-term uncertainties in adaptation costs, analysed in the how sensitive adaptation cost estimates are to climate projections and to the level of damages for a given level of temperature rise.

Analyzing the sensitivity to climate projections is relevant as the relationship between emissions and resulting temperature increase is uncertain. In the results presented in Section 4 we use the median value of temperature projections. Here we look at the adaptation cost level for temperature results that fall within the 16-84 percent range of the frequency distribution of temperature results. Figure A2.1 shows the adaptation cost ranges for 2050 and 2100 for each scenario considering climate uncertainty.

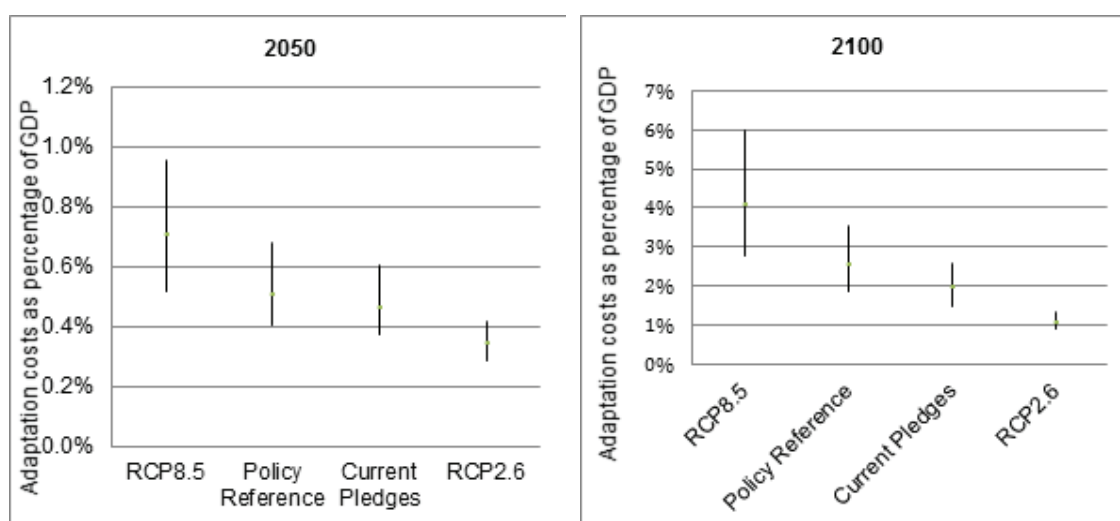


Figure A2.1 Total adaptation costs for all sectors in percentage of GDP for median, 16th and 84th percentile (left panel for the year 2050, right panel for the year 2100). Uncertainty ranges are driven by uncertainty in climate projections, not in damage and adaptation costs. Source: own calculations using the AD-RICE model.

Figure A2.1 shows that adaptation cost could be up to 30% higher and 20% lower for the Policy Reference and Current Pledges scenarios than estimated in Section 4 in 2050. In 2100 the uncertainty range for Policy Reference is higher than for Current Pledges. The Policy Reference scenario shows a range of +35% and -29% whereas Current Pledges a range of +30% and -26%. Interestingly, climate uncertainty plays a much smaller role for adaptation costs for the low emission scenario RCP2.6 than for the other climate scenarios – indicating that not only adaptation costs are much higher for higher emission pathways, but the uncertainty in these costs are also much higher.

As estimating climate change damages is notoriously difficult, we also estimated the sensitivity of these damages on the estimated level of adaptation costs. The range of estimates of climate change damages in the literature is very large (see e.g. Tol (2005)). Within the Integrated Assessment Modelling literature, there are three important damage assessments: those of the PAGE model (Hope 2011), the FUND model (Anthoff and Tol 2013) and the RICE model (Nordhaus 2011). The AD-RICE model applies the damages estimated in the RICE model. The PAGE model estimates are comparable to those of RICE and the FUND estimates are significantly larger for Africa. AD-RICE damage estimates for Africa are 3% of GDP for a 2.5 degree temperature change, while the FUND estimate is 5% for the same level of temperature change. For the sensitivity analysis, we analysed two different damage estimates; a High damages case (200% of the original RICE damages) and a Low damages case (50% of RICE damages). As the damages are more likely to be underestimated than overestimated in our model, we have chosen a larger range of damages above than below our original level. Figure A2.2 shows the resulting levels of adaptation costs. It should be noted that these ranges are mainly meant to show the sensitivity of adaptation cost estimates to damage estimates; therefore, they should not be interpreted as uncertainty ranges of adaptation costs.

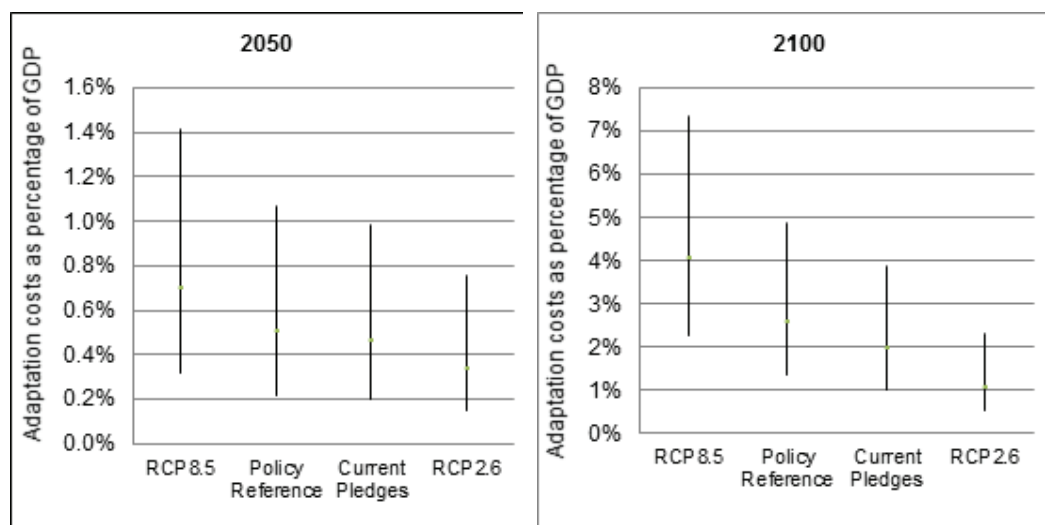


Figure A2.2 Total adaptation costs for all sectors in percentage of GDP for original RICE damages, High damages (200% of RICE) and Low damages (50% of RICE) (left panel for the year 2050, right panel for the year 2100). Uncertainty ranges are driven by uncertainty in climate change damage projections. Source: own calculations using the AD-RICE model.

Figure A2.2 shows that the adaptation costs are strongly dependent on the level of damages. A doubling of damages results in roughly doubling of adaptation costs. The increase in adaptation costs in percentage terms is higher for scenarios with a lower level of temperature change. For all scenarios the increase in adaptation costs with the High damages estimate is lower in percentage terms in 2100 than in 2050. When applying the Low damage estimates adaptation costs decrease by approximately 50% in 2050 and 40% in 2100. Again we see higher effects in scenarios with lower levels of temperature change.

www.unep.org/roa/amcen

